How to optimize cognitive load for learning from animated models

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Voorwoord

Nu mijn proefschrift af is besef ik pas hoe intensief de afgelopen vier jaren zijn geweest. Veel mensen heb ik in die vier jaren mogen ontmoeten die me ondersteund hebben bij het uitvoeren en afronden van mijn promotieonderzoek.

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Chapter 1 - General introduction

Observing how other people behave and then imitating that behavior is an innate way of learning. Imagine, for example, a child who observes the pained expressions of a sibling in the dentist's chair. It is very likely that the child will become fearful for the dentist as well. Young adolescents observe and imitate behavior they see on television (e.g., wearing the same clothes as their television idols). People observe and imitate the social rules of the social groups they want to belong to. This is what social learning theorists call observational or vicarious learning: Watching the behavior of others and observing the consequences it produces for them (Bandura, 1977). This kind of observational learning occurs automatically and has not only proven to be very effective when it comes to learning emotions and social behavior, but also when it comes to intentional learning, that is, learning aimed at specific instructional goals. In this respect it is not astonishing that observational learning has become an effective instructional method in learning motor skills, such as playing tennis, throwing darts, or skiing (Wulf & Shea, 2002). Learning by observing behavior enables us to construct a first representation of the desired behavior without a laborious trial-and-error process.

In modern society, on the other hand, learning becomes increasingly dominated by the need to process constantly changing information, originating from different sources, in order to solve problems in a variety of domains. For example, in Dutch pre-university education students are often required to write papers for which they have to search and interpret all sorts of information from domains like science, social studies, and economics. Such tasks require complex cognitive skills. Modern educational theories emphasize the use of observational learning and modeling with respect to cognitive skills (Collins, Brown, & Newman, 1989; van Merriënboer, 1997). Observational learning and modeling can be regarded as two sides of the same coin: An expert or peer models the desired behavior which from then on can be observed by the learner. In cognitive modeling an expert or peer shows how a problem is solved and why particular methods are most appropriate to do so.

The problem with cognitive skills, such as problem solving skills, is that they are often difficult to observe. When we ask experts to solve a problem in the domain of probability calculation, they will hopefully provide the solution of the problem, but in general they will not express their considerations about possible solution methods, the errors they make, or the consecutive steps they undertake to solve the problem. In other words: The problem was solved, but for a novice there was probably little to learn because most of the actions were performed in the expert's head and thus remained unobservable. In order to become an effective instructional method, cognitive modeling has to explicate the performance of cognitive skills. For example, the experts could have been provided a whiteboard on which they explain how the problem is solved. Sometimes, even telling or writing down how a problem is solved may not be sufficient to make cognitive modeling an instructive experience for novices. This may be the case when the subject matter involves abstract concepts, structures, or processes. For example, in the domain of probability calculation it can be difficult to explicate in words a concept such as 'a drawing without replacement' in a way that is understandable for novices. In this respect, the use of dynamic visualizations such as animations might be helpful to illustrate the concept, for example, by showing a vase with colored balls from which one ball is drawn and put aside. Meanwhile the expert can refer to this situation and explain what the consequences are when a ball is drawn from the vase and not put back. In the last decades, rapid developments in computer and software technology have enabled the use of programmable pedagogical agents that might take over the role of the expert when it comes to supporting learners with explanations and/or guiding their attention to relevant parts of the animation (Atkinson, 2002; Clarebout, Elen, Johnson, & Shaw, 2002; Moreno, 2005). In this thesis the term animated model refers to an instructional arrangement in which (1) an animation is used to display how a problem is solved, while (2) a pedagogical agent simultaneously provides supportive explanations and guidance to the learner.

Typically, complex cognitive skills comprise a multitude of information elements that have to be brought together and integrated in order to understand how the skill is performed. Unfortunately, human cognitive architecture has limitations in the amount of information elements that can be simultaneously processed (Paas, Renkl, & Sweller, 2003, 2004; Sweller, 1988, 1999, 2004; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Sweller, 2005). For example, when learners have to observe an animation and in the meantime understand the explanations that accompany the animation in a domain that is rather new to them, they can easily become overwhelmed. Once they miss a part of the animation and fail to process the presented information, the rest of the animation may become incomprehensible and learning will not occur. So, any design aiming at the instruction of complex cognitive skills has to take the limitations of human cognitive architecture into account.

The goal of cognitive load theory is to develop instructional design guidelines that enable learners to use their cognitive capacity as effectively as possible. For this purpose cognitive load theory discerns three types of cognitive load that can be imposed on working memory. The first type, intrinsic cognitive load, is caused by the complexity of the subject matter and cannot be altered without compromising a sophisticated understanding (Paas et al., 2003, 2004). Also the way that information is presented can impose a cognitive load. The second type, extraneous cognitive load, is imposed on working memory because of poorly designed instructional material. Sometimes, learners have to engage in cognitive activities that do not directly contribute to learning but that are merely used to overcome the deficiencies of the design. One of the most investigated phenomena with respect to extraneous cognitive load is the split-attention effect (Kalyuga, Chandler, & Sweller, 1999; Mayer & Moreno, 1998; Tarmizi & Sweller, 1988). Split attention occurs when information from two (or more) sources must be processed simultaneously in order to derive meaning from subject matter. Take for example the situation of a diagram about assembling a machine for which explanatory text is presented on another page. In order to understand the assemblage of the machine the learner needs both the diagram and the explanatory text. Consequently the learner has to mentally search, match, and integrate both sources of information (i.e., the diagram and the text). It is impossible for the learner to attend both to the diagram and the explanatory text when they are physically separated. This will cause much visual search (constantly alternating between the diagram and the text), which does not contribute to learning and consequently imposes a high extraneous cognitive load on working memory. The third type, germane cognitive load, is imposed when information is presented in such a way that learning is enhanced, for example, because it prompts learners to self-explain the presented solution of a problem.

According to cognitive load theory, any instructional design should consider these three types of cognitive load, that is, decrease extraneous cognitive load and optimize germane cognitive load in such a way that total cognitive load (i.e., extraneous plus germane plus intrinsic load) stays within cognitive capacity limits.

Therefore, the main research question of this thesis is: How to optimize cognitive load for learning from animated models? In particular, the relation between extraneous and germane cognitive load is important, after all, cognitive capacity released by decreasing extraneous load can be employed for activities that ameliorate learning and therefore represent germane cognitive load. Therefore, the first question that will be investigated is: How can learners be prevented from engaging in activities that impose extraneous cognitive load? This is the focus of Chapter 3. However, releasing cognitive capacity by a well-designed learning environment does not guarantee that this cognitive capacity will be used for genuine learning activities. Most of the times learners have to be stimulated to engage in such activities. For this reason, the second question that will be investigated is: How can learners be prompted to engage in activities that impose germane cognitive load, that is, foster genuine learning? This is the focus of Chapters 4 and 5. As will be described in Chapter 2, some factors may weaken or strengthen the effect of design guidelines (irrespective whether they decrease extraneous cognitive load or increase germane cognitive load), or they may even influence the pattern of extraneous and germane cognitive load as well as the factors that effect learners' willingness to engage in such activities. Therefore the focus of the third question is: Which factors moderate the effects of design guidelines? This aspect will be investigated in the Chapters 3 and 5.

Overview of the Chapters

Chapter 2 gives a theoretical account of the characteristics of animated models, that is, the conjecture of cognitive modeling and animations, as well as the beneficial effects of animated models on learning. The larger part of this chapter covers an extensive review of design guidelines that enable learners to manage intrinsic cognitive load, decrease extraneous cognitive load or increase germane cognitive load. Moreover, variables such as motivation are identified as moderators of the effectiveness of the presented design guidelines. The chapter concludes with the presentation of an integrative framework for the design of animated models. This framework is used as the starting point for the empirical studies presented in Chapters 3, 4, and 5.

Chapter 3 focuses on instructional design guidelines that aim at decreasing cognitive load arising from poorly designed instructional material. Three promising design guidelines, namely, pacing, structure of instructional material, and modality are investigated in two separate but related explorative studies. In both studies animated models are used that vary in structure (they can be either segmented or continuous) and pacing (either learner paced or system paced). The first study used spoken explanations. It reveals that learner paced continuous animated models as well as system paced segmented animated models yield higher near transfer performance than learner paced segmented animated models. The second study, using written explanations, shows that learner paced continuous animated models yield higher far transfer performance than both learner paced segmented animated models and system paced continuous animated models. These results indicate that effective learner pacing only occurs when the expected level of control corresponds with the actually given level of control, and when the control concerns continuous animated models rather than their segments.

Chapter 4 takes a closer look at the relation between modality and reflection, using learner paced continuous animated models. The purpose of this study is twofold. To start with, it questions whether reflection prompts can compensate for the modality effect, that is, the better performance when spoken explanations rather than written explanations accompany pictorial information. Secondly, it is designed to investigate whether providing reflection prompts incites learners to engage in relevant learning activities. Four instructional methods are compared varying in modality (spoken and written explanations) and reflection prompts (reflection prompts were provided or not). Reflection prompts yield better transfer performance with written explanations, but have no effect with spoken explanations.

Chapter 5 further explores the most important findings from the studies described in Chapters 3 and 4. First, it tries to replicate the finding of Chapter 3 that learner control is not effective when learners expect some level of learner control beforehand, but cannot actually exert the anticipated control in the learning environment. Second, Chapter 4 showed that reflections on animated models may contribute to relevant learning. Chapter 5 continues on this observation and investigates whether alternating between observation and practice enhances learning. In total six instructional settings are compared comprising level of perceived control (either high or low) and instructional method (either study-practice, practice-study, or study-study). A high level of perceived control yields higher performance on transfer performance, but the alternation between observation and practice does not enhance learning.

Chapter 6, the concluding chapter of this thesis, presents a general discussion of the studies. A review of the results is given, followed by a discussion of the implications for cognitive load theory and theories of multimedia learning. Furthermore, some practical implications for multimedia design are presented and suggestions for future research are described.

Chapter 2 - How to Optimize Learning from Animated Models? A Review of Guidelines based on Cognitive Load

Abstract

Animated models explicate the procedure to reach a problem solution as well as the rationale behind this procedure. For abstract cognitive processes, animations might be beneficial especially when explanations are provided by a supportive pedagogical agent. We argue that animated models can be an effective instructional method provided that they are designed in such a way that cognitive capacity is optimally employed. This review proposes three sets of design guidelines based on cognitive load research. The first set aims at managing the complexity of subject matter. The second set focuses on preventing activities -due to poor design- that obstruct learning. The last set of guidelines incites learners to engage in active and relevant processing of subject matter. Finally, an integrative framework is presented for designing effective animated models.

The current focus on lifelong learning and flexibility in task performance increasingly emphasizes the mastering of complex cognitive skills (Jonassen, 1999). Instructional methods, such as modeling and vicarious learning, in which learners observe how experts perform problem-solving tasks and simultaneously explain the reasoning underlying their actions, fit this focus on complex learning. At the same time, rapid developments in computer and software technology in the last decades have enabled the use of animations to illustrate abstract cognitive processes or concepts (Casey, 1996; Chee, 1995; Collins, 1991) and programmable pedagogical agents to support learners.

We refer to the combined use of animations and pedagogical agents in modeling as animated models. These animated models illustrate the solving of problems such as scientific problems (e.g., solving a problem about gravity), mathematical problems (e.g., probability calculation problems), or search problems (finding information on the Internet). The pedagogical agent functions as a social model and guides the learner through the animation, for example, by moving around the screen and guiding the learner's attention to specific parts of the animation, by addressing the learner in a personalized style and/or by showing which errors typically may occur and how they may be avoided by the learner. For example, in solving a problem in the domain of probability calculation, it is important to know whether it is a 'drawing with or without replacement'. For novices this concept may be rather abstract and difficult to understand. An animation can visualize the concept by showing what is happening in, for instance, a running contest. Imagine that a learner has to calculate the probability that someone correctly guesses the winner of the gold, silver, and bronze medal in a contest of seven runners. The animated model may show a running track with seven competitors who start running. As depicted in Figure 1a, the runner who finishes first can be visibly moved from the running track to the stand.

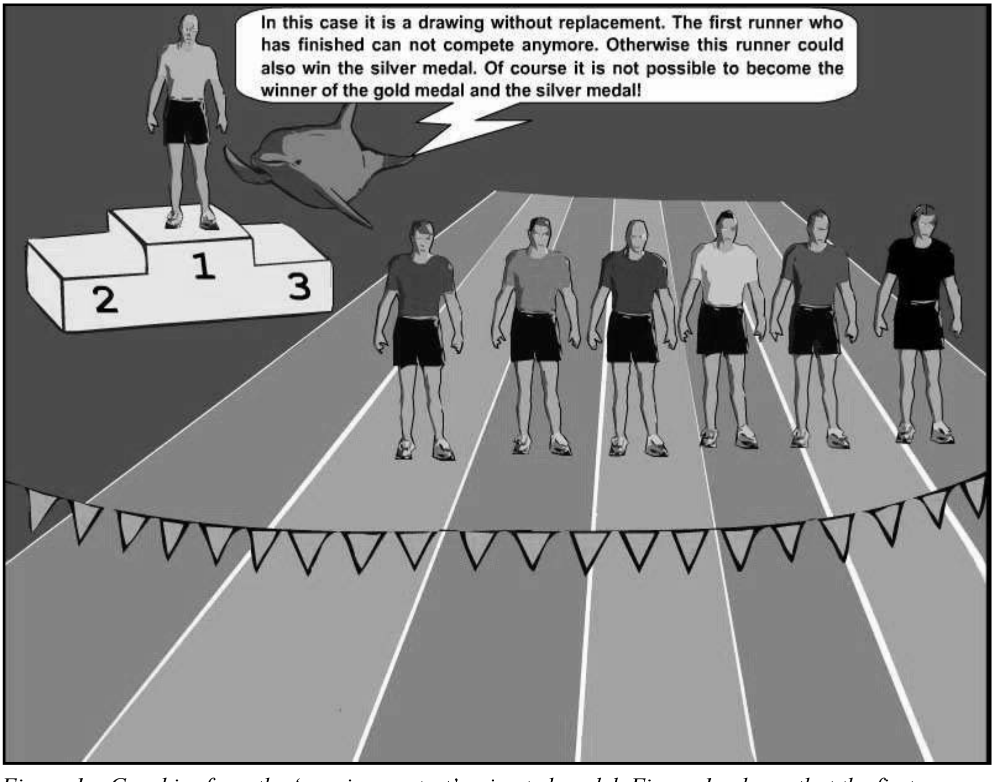

Figure 1a. Graphics from the 'running contest' animated model. Figure 1a shows that the first runner who has finished is moved to the stand. The pedagogical agent (the dolphin) guides the attention to that part.

The pedagogical agent may move to the stand and explain that once a runner has finished as winner (gold medal), this competitor can not compete for the second prize (silver medal). The group of remaining runners then becomes encircled, which is shown in Figure 1b. The pedagogical agent moves to the remaining runners and explains that the number two of the contest will come from these runners. After which the runner who finishes second (silver medal) can be visibly moved from the running track to the stand. This illustrative animated process and its explanation by the pedagogical agent continues until the problem is solved.

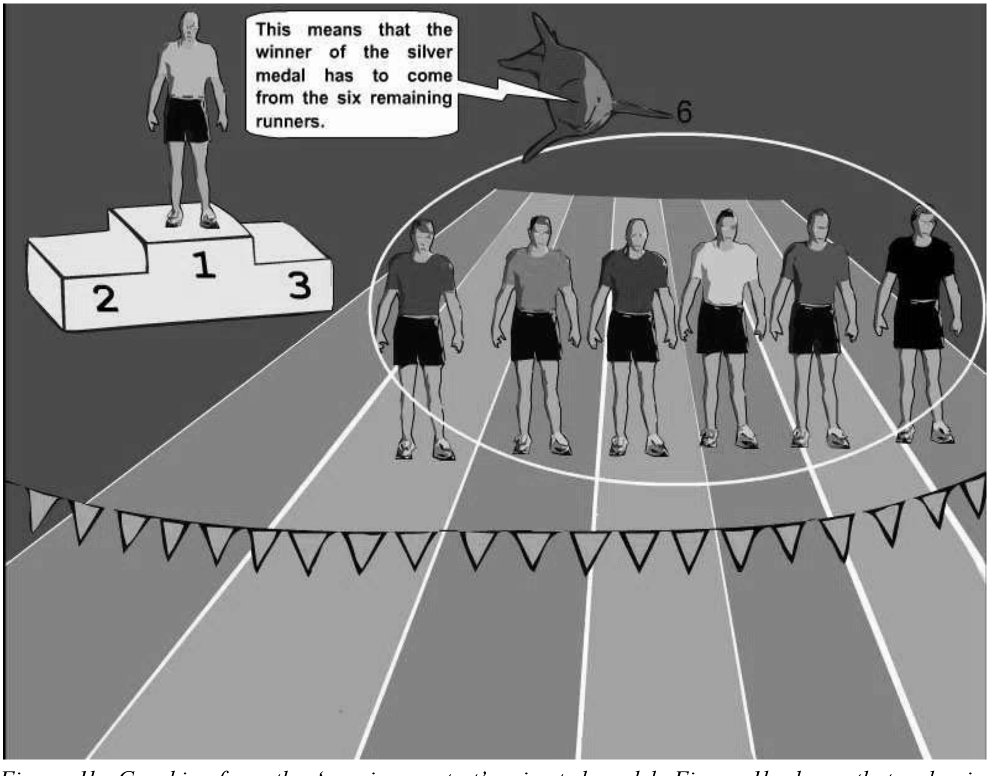

Figure 1b. Graphics from the 'running contest' animated model. Figure 1b shows that only six runners remain. The pedagogical agent (the dolphin) guides the attention to that part.

A potential danger of showing the performance of a complex task with visualizations and verbal explanations is that the limited cognitive capacity of learners might become overloaded. Cognitive load theory emphasizes this limitation as an important determinant for the effective use of instructional methods (Paas, Renkl, Sweller, 2003, 2004; Sweller, 1988, 1999, 2004; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Sweller, 2005). In this paper we argue that animated models can be an effective instructional method, provided that they are designed in such a way that cognitive capacity is optimally employed. We will propose a set of design guidelines to accomplish this. For this purpose we selected design guidelines from review publications of leading researchers in the field (e.g., Mayer, 2001, 2005a, 2005b, 2005c; Moreno, 2005; Mayer & Moreno, 2002, 2003; Sweller, 1999, 2005, 2006; Sweller et al, 1998; van Merriënboer & Sweller, 2005). We also conducted a literature search with these design guidelines as search terms in the PsycINFO and EJS E-journals databases. Additionally, we also searched in these databases with broader descriptors, such as, 'cognitive load', 'animations', 'dynamic visualizations', and 'multimedia'. In cases that too much output was generated we further limited the search results with terms, such as, 'learning', 'instruction', and 'training'. Finally, the resulting scholarly output was then narrowed by selecting studies that were applicable to animated models.

In this paper we will first give an outline of cognitive load theory. Second, we will further elaborate on the nature of animated models, that is, attention will be paid to cognitive modeling, animations, and pedagogical agents. Third, design guidelines are proposed that enable learners to engage in more effective learning from animated models. The last section draws some conclusions and provides directions for further research.

Cognitive Load Theory

Cognitive load theory tries to align the structure of information and the way it is presented with human cognitive architecture. In order for learning to commence, people have to process information and the degree in which the complexity of information varies is a qualifying factor. For the processing of information two structures in human cognitive architecture are crucial. Working memory, where all conscious processing of information takes place, only has a limited processing capacity that is by far inadequate to meet the complexity of information learners face in modern learning environments. The second structure, long-term memory, is a knowledge base with a virtually unlimited capacity that can serve as added processing capacity by means of schemas, that is, cognitive structures in which separate elements are aggregated in one specialized element that can be processed by working memory as a single element (Paas et al., 2003). In a complex skill like driving a car, more experienced drivers continuously make use of such aggregated elements (e.g., changing gears) that can be processed by working memory as one element. Less experienced drivers need to bring the separate elements, such as declutching, shifting the gear and engaging the clutch, one by one into working memory in order to successfully change gears. The acquisition and automation of such schemas- so that they can be processed unconsciously- is important because it further optimizes the processing capacity of working memory.

From the perspective of instructional design, information can impose a cognitive load in three ways. First of all there is cognitive load that depends on the element interactivity of the subject matter; complex information consists of a multitude of elements that interact with each other. One can only speak of 'understanding' such complex information when not only the separate elements are processed, but also the way they interact (Chandler & Sweller, 1994, 1996). For instance, in acquiring a foreign language, learning word pairs is associated with less element interactivity than understanding the grammar of a sentence. For learning word pairs, only two elements need to be active in working memory. However, for understanding a sentence, not only the words in the sentence have to be held in working memory, but also their grammatical relationships. For example, in order to understand that a sentence like ‘Two children are sitting on a couch’ is correct, but that ‘Two children is sitting on a couch’ is not, the learner not only has to hold the separate words in working memory but also the grammatical parts like subject and verb and their relation (i.e., the plural of the subjects has a consequence for the conjugation of the verb). In cognitive load theory this is called intrinsic cognitive load and it can be regarded as a necessary base load, because it cannot be reduced without compromising full understanding. The more complex a skill, the higher the intrinsic cognitive load because of higher element interactivity.

Second, the way that information is presented can also impose a cognitive load. Extraneous or ineffective cognitive load is imposed on working memory because of poorly designed instructional material. Sometimes, learners have to engage in cognitive activities that do not directly contribute to learning but that are used to overcome the deficiencies of the design. One of the most investigated phenomena with respect to extraneous cognitive load is the split-attention effect (Kalyuga, Chandler, & Sweller, 1999; Mayer & Moreno, 1998; Tarmizi & Sweller, 1988), which occurs when two (or more) sources of information must be processed simultaneously in order to derive meaning from subject matter. Take for example the situation of a diagram about assembling a machine for which explanatory text is presented on another page. The learner has to mentally search, match and integrate both sources of information, which imposes a high extraneous cognitive load on working memory. This high load might interfere with learning.

Third, germane or effective cognitive load is imposed when information is presented in such a way that learning is enhanced, that is, when it facilitates the construction and/or automation of cognitive schemas. The assumption is that active processing will yield germane cognitive load. In this respect, the generation of self-explanations has proven to be an effective cognitive activity that enhances learning (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Renkl, 1997; Renkl & Atkinson, 2002). Take for example an expert who has shown how to solve a problem in probability calculation. Novices might engage in relevant learning activities when they are incited to explain the observed problem-solving process and the resulting problem solution to themselves, and in this way acquire or refine their cognitive schemas.

The three types of cognitive load are not isolated but act as additive components. The combined load of these components cannot exceed the available cognitive capacity and, consequently, the high load of one component is at the cost of another component. When intrinsic cognitive load is high it becomes important to decrease extraneous cognitive load, otherwise the combination of both might exceed the maximum cognitive capacity and thus prevent effective or germane activities to occur. From an instructional design point of view, especially extraneous cognitive load and germane cognitive load should be considered as communicating vessels as the reduction of extraneous cognitive load can free cognitive resources for an increase in germane cognitive load (Paas et al., 2003).

Modeling

The modeling and the vicarious learning literature emphasize that learning by observing experts (or advanced novices) who display their performance of physical and/or cognitive skills can enhance learning (Bandura, 1976, Collins, Brown, & Newman, 1989; Cox, McKendree, Tobin, Lee, Mayes, 1999; van Merriënboer, 1997). Two arguments support this assertion. First, when observing an expert performing a complex task in which both knowledge and skills are integrated, the learner can construct an adequate cognitive representation. This representation guides appropriate performance and enables the learner to mentally (or physically) rehearse the task, which in turn refines the initial representation. Second, compared with other instructional methods like worked-out solutions, learning by observation of a model might be beneficial, because it not only shows what is happening, but also why this is happening (Collins, 1991; van Gog, Paas, & van Merriënboer, 2004). Problem solving, for example, can be regarded as the application of several steps in order to solve the problem, but this approach does not take into account why some steps are chosen and others are not, to solve the problem. In this way more generalized schemas might be constructed that can be applied in a variety of contexts or problem formats. Moreover, the expert might tell about false starts and dead ends and enable the observer to learn what kind of response to avoid without the need of making the error themselves (Bandura, 1976; Cox et al., 1999).

According to Collins et al. (1989), expert performance can be divided in the performance of physical skills and processes and the performance of cognitive skills and processes. On the one hand, action-oriented skills like those applied in learning to write or sports such as skiing, playing tennis and throwing darts (Kitsantas, Zimmerman, & Cleary, 2000; Zimmerman & Kitsantas, 2002, see for a review, Wetzel, Radtke, & Stern, 1994) typically involve behavioral modeling, that is, the expert shows the desired physical performance. Modeling of cognitive skills and processes, on the other hand, requires the explication of considerations, thoughts and reasons that underlie the performance of actions or choices. Problem solving (Jonassen, 1999) and cognitive behavior modification (Meichenbaum, 1977) are examples of domains that essentially involve cognitive modeling.

It is a problem, regarding skills and processes in the cognitive domain, that they are not readily observable. When a novice observes an expert solving a problem, all the thoughts, considerations, and reasons might be traced back or concluded from the results, but the observer cannot actually perceive the cognitive performance. To overcome this problem, the cognitive skills and processes of the expert that occur internally have to be externalized. In their description of cognitive apprenticeship learning, Collins et al. (1989) discuss some approaches in which the externalization of cognitive skills is practiced by having teachers, the models, speak out aloud their considerations with respect to heuristics (e.g., rules of thumb) and control processes in fields like writing and mathematics.

When abstract concepts or processes are involved that have no physical counterpart, cognitive modeling might become difficult. For example, in debugging, which is an important aspect of learning computer programming, a novice programmer tries to find out what happens when an error occurs in the program code. Cognitive modeling could be used to show how an expert programmer finds out what specific cause-and-effect relations exist in the program code and which reasoning underlies these considerations. However, it is difficult to externalize the expert's considerations about concepts such as readability, robustness, and processes such as inheritance of properties in such a way that it helps learners to construct a mental representation. In this respect, the use of dynamic visualizations such as animations might be helpful to illustrate these concepts and processes.

Animations

One of the most comprehensive theories about multimedia learning is Mayer's cognitive theory of multimedia learning (Mayer, 2001, Mayer & Moreno, 2003). This theory can be considered a further extension of dual coding theory from which it adopts the dual channel assumption. This assumption implies that information is processed in two separate channels: A verbal system, which basically comprises written language and spoken language, and a nonverbal system, which processes pictorial materials (Clark & Paivio, 1991, Paivio, 1986). A fundamental prediction of dual coding theory is that both systems are additive and that people learn better when the presented information is encoded both verbally and visually rather than in one system only. Information that has been encoded in two ways can be retrieved from memory more easily. Whereas the vast majority of dual coding theory research has been conducted with static visualizations, the cognitive theory of multimedia learning has focused on dynamic visualizations. Probably the most widespread type of a dynamic visualization is the animation that can be regarded as the presentation of frames in such a way that each frame appears as an alteration of the previous one, with a speed that creates the illusion of apparent motion (Rieber & Kini, 1991). Often, the animation is combined with explanatory verbal information. The cognitive theory of multimedia learning argues that different mental representations have to be constructed from verbal and pictorial information, but simultaneously these representations have to be actively integrated in order for meaningful learning to commence (Mayer, 2001; Mayer & Moreno, 2003; Mayer & Sims, 1994).

Four characteristics of animations can be found that are relevant for (cognitive) modeling. The first characteristic is that animations can present information that changes with time, such as the working of a device or the explanation of a procedure by movement of objects in the animation (Ainsworth & VanLabeke, 2004; Hegarty, 2004, Tversky, Morrison, & Betrancourt, 2002; Rieber, 1990; Weiss, Knowlton, & Morrison, 2002). Although the movement of objects is an important type of change within an animation, yet other types of changes can be distinguished. An interesting division is made by Lowe (1999, 2003), who conceives animations as consisting of one or more objects that may undergo several types of changes. First of all there are transformations that can be regarded as changes in properties of objects like color, shape, and size. Subsequently there are translations, which refer to movements of objects on the screen. Finally there are transitions that concern the appearance and/or disappearance of objects. These three types of changes can occur in an isolated fashion (e.g., an object starts flashing), but will typically occur together (e.g., an object starts flashing and moving). In complex animations, more objects exist and each object can have its own regime of changes. For example, in a meteorological animation several high-pressure and low-pressure areas may exist that move into several directions (i.e., translations), expand or shrink (i.e., transformations), and arise or disintegrate (i.e., transitions). From a cognitive load perspective, the dispersion of information in parts that follow each other sequentially or that are presented simultaneously might be problematic: Once a part of the information is missed or only partly processed, the remaining parts might become incomprehensible. In order to build a coherent representation, the learner has to hold and integrate information from these different parts in working memory and then store it in long-term memory (LTM), otherwise they will not be able to retrieve the information in that part. If the following part of the animation has to be processed before the earlier part is stored in LTM, this new information will interfere with remembering the information in the earlier part. This phenomenon is called retroactive inhibition (Baddeley, 1997) and may be reinforced by the fact that people have limited time to study each part of an animation because of its transient nature (Lowe, 1999, 2003). In the case of poor design of the animation, that is, when extraneous cognitive load is involved, retroactive inhibition due to limited processing time uses up cognitive resources that could better be used for building the cognitive representation.

A second characteristic of animations is that they can be seen as depictive external representations (Schnotz, 2002). The depictive nature of animations enables the visualization of concrete concepts, such as the working of a bicycle pump that can be depicted by the animation of its working, or of abstract concepts that are represented by concrete events, such as the term ‘drawing without replacement’ in probability calculation that can be depicted by drawing marbles from a vase without returning them. Moreover, an advantage of animations is that they can be shaped, distorted, or manipulated by showing an object, for example, from multiple perspectives or by making it larger or smaller (Hegarty, 2004; Schwan & Riempp, 2004).

The third characteristic is that the animation's salient features, such as motion and flashing, can focus the learner's attention to relevant parts of the screen (Park & Hopkins, 1993; Wetzel et al., 1994). This can be relevant for novices who might be overwhelmed by complex animations (Rieber, 1990). In the animation of a complex system, for example, a flashing arrow could highlight the critical features of the system.

A fourth characteristic reported by a number of researchers is that animations can motivate learners by their cosmetic appeal (Shah & Freedman, 2003; Weiss et al., 2002). For example, animated agents can be used to reduce potentially upsetting information and popular cartoon figures can be used to engage young learners in learning (Wetzel et al., 1994).

These four characteristics make animations potentially useful in conjunction with cognitive modeling. Take, for example, an animation in which an expert is telling how meteorological data have to be interpreted in order to give a sound weather report. The expert verbalizes that several low-pressure and high-pressure areas exist, how they interact with each other and how they are geographically related to each other. An animation could visualize this situation and make it easier for a novice observer to make a mental representation of it. Moreover, when the expert is stressing the importance of a low-pressure area that is shrinking, the animation could focus the learner's attention on this by zooming in on the particular area.

Although dynamic visualizations seem very appealing, several studies and reviews have shown that the dynamic visualizations are -at best- not more effective and occasionally even less effective than static visualizations. In an extensive review, Tversky et al. (2002) reported that in general dynamic visualizations were not more effective than static visualizations. In the cases that they were more effective this could be ascribed to more detailed information that was available in the dynamic visualizations or because of the benefits from study procedures, such as prediction, that were not available in the static visualizations. In the domain of mechanical systems, Hegarty, Kriz, and Cate (2003) compared learning from animated graphics with static diagrams and concluded that both types of visualizations resulted in better learning but that the animated graphics did not lead to superior performance. In other cases it was found that the use of dynamic visualizations led to more time spent on instruction without corresponding gains in learning outcomes (Koroghlanian & Klein, 2004). These studies make clear that there is no strong evidence to ground any claim that dynamic visualizations are better than static visualizations. In their analysis, Tversky et al (2002) formulated two principles that specify the conditions under which dynamic visualizations may be effective, although not necessarily more effective than static visualizations. First, they postulate the apprehension principle, stating that the structure and content of a dynamic visualization should be readily perceivable and comprehensible (e.g., a dynamic visualization should not go too fast). Second, the congruence principle explains that the structure of a dynamic visualization should correspond with the way people conceive the processes or procedures that are visualized. For example, if operating a machine is conceived as a sequence of discrete steps, a dynamic visualization should visualize it that way.

We concur with the notion that we should focus on identifying the conditions under which dynamic visualizations might indeed promote learning (Hegarty, 2004; Mayer & Moreno, 2002; Tversky et al, 2002). Furthermore, we contend that dynamic visualizations might become more effective when they are designed in such a way that cognitive capacity is optimally employed. In this respect, a series of four experiments conducted by Mayer, Hegarty, Mayer, and Campbell (2005) is of interest. Overall, the results of these experiments showed that dynamic visualizations (narrated animations) resulted in poorer learning than static visualizations (illustrations on paper). Although Mayer et al. explained these findings in terms of the cognitive theory of multimedia learning, we contend that the dynamic visualizations in these experiments were not designed in such a way that learners' cognitive capacity was optimally employed. We concur with the authors' conclusion that the static visualizations were learner-paced and segmented in meaningful units, whereas the dynamic visualizations were computer-paced and continuous. But as we will argue later, we consider both learner-pacing and segmentation as design guidelines that can also be used in combination with dynamic visualizations in order to decrease extraneous cognitive load and thus release cognitive capacity for genuine learning.

Animated Pedagogical Agents

Cognitive modeling involves complex skills that often have to be applied in specific contexts in which a problem has to be examined from several perspectives.

For novices this can pose a problem and support given by a pedagogical agent (e.g., a tutor, a peer student, a software agent) might be helpful. Animated pedagogical agents are computerized characters that appear on the screen and support the learner, which include guiding, coaching, and providing feedback, as they engage in a task by verbal (e.g., explanations) as well as nonverbal communication, such as, gazing and gesturing (Atkinson, 2002; Clarebout, Elen, Johnson, & Shaw, 2002; Moreno, 2005). These animated pedagogical agents can be human-like (e.g., “Herman the Bug”, an insect with some facial expression used in several research projects) or not (e.g., the well-known “Paperclip” of Microsoft Office).

The last five years several reviews and studies concerning the instructional value of animated pedagogical agents have been published. An instructional advantage put forward by researchers is the potential of animated pedagogical agents to motivate learners (Dehn & van Mulken, 2000; Moreno, Mayer, Spires, & Hiller, 2001; Moundridou & Virvou, 2002). For example, Moreno et al. (2001) found that learners in a learning environment with an animated pedagogical agent were more motivated and interested. Moreno and colleagues explained this motivation effect with the social agency theory that assumes that learners in a social-agent learning environment tend to work harder. Social agency theory was derived from the media equation hypothesis (Reeves & Nass, 1996), which claims that people view interaction with media, such as computers and software, as interaction with humans and that therefore social rules that apply for human-to-human interaction also apply for human-media interaction. According to social agency theory, multimedia instruction can be regarded as information delivery or as a social event. When social cues are incorporated in the multimedia instruction, people will interpret the interaction with the computer as a social event. The theory further argues that these social cues will prime social conversation and so engage the learner in efforts to make sense of what the multimedia instruction is saying (Moreno et al., 2001). Furthermore, Moundridou and Virvou (2002) found that an animated pedagogical agent made learning in a learning environment with algebraic word problems easier and more pleasant in the perception of the learners.

Another didactical function, which is enabled by the current state of technology, is that animated pedagogical agents can be programmed to adapt to the characteristics of a specific learner or to the context in which a task is performed (Clarebout et al., 2002, Clark & Choi, 2005). For example, the agent could scaffold the amount of support and guidance that is provided, by performing parts of the task that learners cannot perform on their own, by coaching, and by providing hints and feedback specific for a learner.

Reviews regarding the benefits of animated pedagogical agents report mixed results: In some empirical studies animated pedagogical agents yield better learning (e.g., Moreno et al., 2001), whereas other studies did not find these learning benefits (Clark & Choi, 2005; Dehn & van Mulken, 2000). We contend that animated pedagogical agents must be applied carefully. To start with, it seems that the effect of these agents is domain-specific. For example, in their review Dehn and van Mulken (2000) concluded that the effect of an anthropomorphized agent on entertainment value is domain-specific. In a technical system an anthropomorphized animated pedagogical agent was more entertaining than an agent with a geometrical interface, whereas in a system for introducing new employees in an organization no difference in entertainment value was found. The same pattern was found for assessed task difficulty: When technical information was presented, lower task difficulty was reported when the information was referred to by an animated agent than when it was referred to by a pointing arrow. Again, for the introduction of new employees no difference in perceived task difficulty was found between the animated agent and the pointing arrow.

A second comment pertains to the preference of learners for animated pedagogical agents. Craig, Grasser, Sullies, and Gholson (2004), for example, investigated the relation between different types of affect, such as boredom, flow and confusion and learning in a learning environment about computer literacy which included an animated conversational agent which was capable of synthesized speech, gestures, and facial expressions. While learners worked in the learning environment, their emotions were tracked and coded. It was found that affects like confusion and flow correlated positively with learning gains, whereas an affect like boredom correlated negatively with learning gains. Trying to ignore an animated pedagogical agent that doesn’t motivate learners, but bores or even annoys them, imposes an ineffective cognitive load (i.e., extraneous load).

To conclude, we contend that the processing of a sophisticated animated pedagogical agent with many salient details might require so much cognitive capacity that little remains for processing the actual subject matter. We believe that animated pedagogical agents can be beneficial when they are designed according to the guidelines provided by cognitive load theory.

Design Guidelines for Animated Models

The purpose of the remainder of this article is to propose guidelines for decreasing extraneous and, if necessary, intrinsic cognitive load as well as for increasing germane cognitive load. First, some guidelines will be discussed to decrease intrinsic cognitive load. Guidelines that primarily aim at reducing or managing the element interactivity of subject matter are classified under this category. Second, when guidelines reduce activities that obstruct learning (e.g., visual search caused by split-attention effects) they are listed as guidelines to decrease extraneous cognitive load. These guidelines may help to free up processing resources that can subsequently be devoted to learning. Finally, design guidelines are presented to increase germane cognitive load. These guidelines may help to make good use of the cognitive resources that have become available through decreasing intrinsic and/or extraneous cognitive load. The criterion for these guidelines is that they should prompt learners to engage in active processing of subject matter. It should be noted that some guidelines may have an effect on more than one type of cognitive load. For example, element interactivity may be reduced by providing a simple animated model. It is obvious that such a simple animated model may also involve less visual search and thus cause less extraneous cognitive load. In these cases the guideline will be classified under the category it primarily aims at. In addition to this, guidelines may be categorized differently in other classifications. For example, Mayer (2005a) regards segmentation as a guideline for decreasing intrinsic cognitive load, whereas in this review it is assumed to decreases extraneous cognitive load. In these cases we briefly discuss these differences. For each guideline an example will be provided.

For the sake of clarity we will apply each guideline to the ‘running contest’ animated model which was already described in the introduction. In this animated model seven runners compete for the gold, silver, and bronze medal. While the competitors start running, a pedagogical agent explains the steps that are needed to calculate the probability that someone correctly guesses the winners of the gold, silver, and bronze medal. When the first competitor has finished, the runner is moved to the number 1 position of the stand that is positioned beside the running track (the same is true for the numbers 2, and 3). Table 1 presents a summary of the proposed guidelines.

Table 1. Summary of design guidelines for animated models

Guideline	Description	Example
Decrease intrinsic cognitive load		
1. sequence of simple-to-complex whole tasks	Present animated models that require the integration of different skills and knowledge. Start with simple animated models with low element interactivity and gradually increase the complexity	Make the animated model more complex by calculating the probability that the numbers one to seven are guessed correctly, instead of only the gold, silver, and bronze medal
2. Pretraining	First present isolated components before the interaction between these components is instructed in the animated model	First present definitions of terms, such as, drawing without replacement, order is relevant. Then present the animated model in which these terms interact
Decrease extraneous cognitive load		
1. Pacing	Allow learners to adapt the tempo of presentation of the animated model to their cognitive needs	Learners may pause, continue or move forward/backward in the animated model
2. Segmentation	Divide animated models in several segments in which each segment corresponds with an important part of a procedure or process	Segment 1 determines whether it is a ‘drawing with replacement or not’; segment 2 determines whether the ‘order is relevant or not’; in segment 3 the problem solving method is chosen, etc.
3. Modality principle	Present textual explanations in animated models in spoken format	Use spoken explanations
4. Contiguity principle	Present textual explanations in animated models contiguously in time or space	When the expert points to the runner on the stand, the explanation that this competitor can not compete anymore for the silver medal must be spoken at the same time

Table 1. Summary of design guidelines for animated models (continued)

Guideline	Description	Example
5. Signaling or cueing	Present cues to prevent visual search in animated models	The pedagogical agent first points to the runner on the stand and then to the remaining runners (who start running again) to focus the attention of the learner to the parts of the animated model where it is visualized that this is a drawing without replacement
Increase germane cognitive load		
1.Expectancy-driven methods	Present opportunities in animated models to predict the next step in a process	The learner is prompted to answer the question ‘Is this a drawing with or without replacement?’. After answering the animated model continues
2. Subgoaling	Prompt learners in animated models to group coherent steps of a procedure into a meaningful subgoal	At the end of the segment in which it is concluded whether it is a drawing with or without replacement, the learner can be prompted to formulate a subgoal by asking ‘Which factor(s) determine whether it is a drawing with or without replacement?’
3. Imagination	Stimulate learners to imagine procedures and concepts that are used in animated models	Learners first study the ‘running contest’ animated model and then have to imagine performing the shown problem solving procedure
4. Variability	Present problems that vary in relevant features	Adapt the animated model in such a way that 7 runners start, but that after the first runner has finished, one of the competitors drops out. This has a consequence for the problem solving method

Note: In the column ‘Example’, the guidelines are applied to the ‘running contest’ animated model. In this animated model, seven runners are at a running track. They compete with each other for the golden, silver, and bronze medal.

Guidelines for Decreasing Intrinsic Cognitive Load

The first guideline to decrease intrinsic cognitive load focuses on scaffolding learners when they perform so-called whole tasks. In whole tasks, learners have to coordinate and integrate different skills and knowledge so that they develop a holistic view on the nature of the task (van Merriënboer, 1997). However, for novices complex whole tasks may be overwhelming and impose a high level of intrinsic cognitive load. Therefore, a sequence of simple-to-complex whole tasks is proposed starting with relatively simple whole tasks that enable learners to construct and automate schemas before they commence with more complex whole tasks (van Merriënboer, Kirschner, & Kester, 2003; van Merriënboer & Sweller, 2005).

A complex skill like "searching for literature", for example, can be simplified by defining conditions that will make a task more simple without compromising its whole task nature, such as the clearness of the concepts used, the number of the articles in the domain, the number of databases that will be searched for relevant literature, the type of search, and the number of search terms. The simplest whole task that learners are initially confronted with pertains to a domain with clearly defined concepts, in which search terms on keywords that are not interconnected by 'and' or 'or' operators results in a limited number of articles, originating from only one database. Whole tasks with increasing complexity can be constructed by variations in these conditions, for example, learners have to conduct a search in several databases with many search terms that have to be connected with 'and' and 'or' operators (van Merriënboer et al., 2003).

With respect to the 'running contest' animated model an additional animated model with more complex conditions can be provided. One of the conditions that determine the complexity of probability calculation is the number of individual events that have to be considered. In the original 'running contest' animated model three of such events had to be taken into account, that is, the golden, silver, and bronze medal. Then, the additional animated model could be made more complex by increasing the number of individual events, for example, by having to calculate the probability that someone guesses the numbers one to seven in the running match correctly.

A second guideline releases the whole-task approach and can be characterized as pretraining, because it departs from the view that first isolated components have to be instructed before learners are exposed to the interaction of these components (Mayer, 2005a; Mayer & Moreno, 2003). For example, in meteorology learners first are instructed what high-pressure and low-pressure systems are before they learn how these systems interact with each other and determine the weather in a region. Pollock, Chandler, and Sweller (2002, Experiments 1 and 3) reduced the complexity in the domain of testing electrical safety by presenting part of the subject matter in a pretraining. In the first phase only the isolated components were presented to enable novices to construct a schema of these components. In the second phase all informational components as well as the interactions between them were explained. It should be noted that the kind of reduction in the first phase may lead to an initial decrease in the learner's understanding, which is compensated for by an increase in understanding in the second phase. Pollock et al. found that a group of novices exposed to a similar two-phase instruction outperformed a group that was exposed twice to an interacting- components -only instruction (there was no difference in instruction time). Similar results were found by Mayer, Mathias, and Wetzell (2002) with learning how brakes and pumps work. Learners performed better on transfer when they first received a short training about the names and behaviors of the components, followed by a narrated animation about the way these components interacted. Finally, in a cause-and-effect system (origin of lightning), Mayer and Chandler (2001, Experiment 1) first had novices learn the isolated components, which enabled them to build a rudimentary schema, followed by an instructional phase in which they learned about the causal relation between these components. It was found that learners who followed this treatment scored better on transfer than learners who received either twice an instructional format in which the components and their causal relations were integrated, or a group who received first instruction about the causal relations between the components followed by instruction of the components only. A problem with this study was that instruction time was not recorded and that it can not be concluded definitely that the experimental treatment caused the effect or a prolonged instruction time. In probability calculation problems, such as the one used in the 'running contest' animated model, the solution method depends on the interaction between 'drawing with replacement or not' and 'order relevant or not'. Then, in a pretraining strategy first definitions of concepts like 'drawing with replacement or not' and 'order relevant or not' as well as relevant formulas are instructed. After that the 'running contest' animated model can be studied in which it is shown how 'drawing with replacement or not' and 'order relevant or not' interact and determine which method can be used to solve this problem.

In conclusion, pretraining seems more appropriate for animated models in which causal relations prevail, such as, cause-and-effect systems or the working of devices, but less appropriate for animated models in which procedures are involved. Consequently, pretraining seems less suitable to apply in the 'running contest' animated model.

Guidelines for Decreasing Extraneous Cognitive Load

The first guideline, pacing, involves the control over the continuation of the presentation of instructional material, which can be exerted by either the learner or the system (e.g., a computer). Learner pacing might enable learners to adapt the presentation of instructional material to their cognitive needs (e.g., by pausing the instruction or going backward in the material). Schwan and Riempp (2004) showed in a study with a video about nautical knotting that pacing (instantiated by accelerating, decelerating, stopping or repeating the video) was heavily used, especially with increasing knot difficulty. The more difficult the knots became, the more pacing was used, which resulted in a better understanding of the underlying processes, that is, less practice time was needed to reproduce the knots correctly. Other studies (Mayer & Chandler, Experiment 2, 2001; Mayer, Dow, & Mayer, Experiment 2a and 2b, 2003) reported a learner pacing effect, but the effect of either instruction time on transfer performance or the segmentation of instructional material was not taken into account. It is not clear whether the positive effects can be ascribed to learner-pacing, the prolonged instruction time, or the segmentation of instructional material. On the other hand, there are studies in which pacing was a manipulated factor that report mixed results. Recently, Moreno and Valdez (2005, Experiment 2) failed to find a learning advantage on transfer for learner pacing compared with system pacing. The learner-paced group even took less time than the system-paced group, which seems to suggest that learners in the former condition might not have been motivated enough to work through the learning environment. Tabbers, Martens and van Merriënboer (2004) further qualified the pacing effect as they found that with learner pacing, learners who received written explanations outperformed learners who received spoken explanations on transfer test performance. Possibly, the absence of time pressure for learner pacing enabled learners to process the written text strategically (i.e., scan the text, reread). In the 'running contest' animated model, a limited version of learner pacing, may enable learners to pause and continue the animated model. In a more sophisticated version of learner pacing, learners might also move forward or backward in the animated model (e.g., with a slider bar they can go quickly forward by dragging the slider to the right).

To conclude, the findings seem to suggest that considerations regarding pacing, such as when to apply pacing, might interrupt the processing of information and thus impose such an extraneous load on the cognitive system of novices that little resources remain for learning. Possibly, pacing should be implemented in conjunction with other guidelines, such as segmentation.

A second guideline is to apply segmentation. The segmentation of an event can be based on the model of event perception (Zacks & Tversky, 2001), which assumes that a continuous event is cognitively represented in a highly structured manner. According to the model of event perception, events can be decomposed into segments that subsequently consist of activity steps. Zacks and Tversky provided evidence that activity steps with high informative value correctly characterized the segment of which they were part, whereas activity steps with low informative value failed to represent that segment. The places in the event where these highly-informative activity steps occur are regarded as 'breakpoints.' With respect to learning procedural tasks (e.g., upgrading a computer) from videos, Schwan and Garsoffky (2004) found evidence that these breakpoints are important: They observed that summaries of procedural tasks based on breakpoints were perceived as equally comprehensible as the complete video, but as more comprehensible than summaries based on non-breakpoints. Moreover, they found that the omission of breakpoints resulted in higher cognitive costs because the event structure was lost and participants had to use their cognitive resources to cope with this break in the coherence of the event. This observation is in line with Schwan, Garsoffky, and Hesse (2000), who argued that film-cuts on places where breakpoints occur can facilitate the cognitive processing of breakpoints as they make these more salient. Because less effort is needed to search for breakpoints, more cognitive resources are available for building a cognitive representation. Furthermore, in a cause-and-effect system (origin of lightning), Mayer and Chandler (2001, Experiment 2) reported that learners who received an animation that was divided into a set of segments scored better on transfer than learners who received a continuous animation. It should be noted, however, that segmentation is only effective when the learner has completed the processing of one particular segment before the next segment is presented. In the 'running contest' animated model, the problem solving process can be regarded as an event. Each segment could correspond with one important step in the problem solving process. For example, in segment 1 it is determined whether it is a ‘drawing with replacement or not’; segment 2 determines whether the ‘order is relevant or not’; based on this information the problem solving method is chosen in segment 3; in segment 4 the problem solving method is applied, and finally, in segment 5 the probability is calculated.

A final remark concerns the fact that other perspectives exist on the classification of the segmentation guideline. Whereas in this review segmentation is regarded as a technique that may help learners to prevent visual search, there is also the point of view that regards segmentation as a technique for decreasing intrinsic load (Mayer, 2005a, Mayer & Moreno, 2003). In the present review, segmentation is considered in isolation, contrary to the other classification in which segmentation is applied in conjunction with pacing. We agree that segmentation in combination with learner pacing may help learners to overcome the complexity of subject matter and in that respect decrease intrinsic cognitive load.

The third design guideline is the application of the modality principle. Modality refers to the sensory mode in which verbal code is presented, either in a written or spoken format (Penney, 1989). Research with respect to the modality of presentation has indicated that spoken verbal explanations are generally superior to written explanations, when used in combination with pictorial learning material (Mayer, 2005a; Moreno & Mayer, 1999; Mousavi, Low, & Sweller, 1995; Sweller et al., 1998; see for a meta-analysis: Ginns, 2005). This is ascribed to the modality principle: The combined use of the visual channel for pictorial learning material and the verbal channel for the explanation of this material increases effective working memory capacity and so facilitates learning. More recently the modality principle was further qualified. To start with, Tabbers (2002) found that pacing was an important factor as written explanatory text was more effective than spoken explanatory text when learners had control over the pacing of the presentation. Possibly, the absence of time pressure for learner-controlled pacing offers the possibility to process the written text strategically. Secondly, Mayer, Sobko, and Mautone (2003) observed that learners who heard a spoken explanation in a standard accent performed better on transfer than learners who heard the same explanation with a foreign accent (Experiment 1). Similarly, they found that a human voice resulted in better transfer than a synthesized voice (Experiment 2). Spoken explanations can be used if the ‘running contest’ animated model requires so much visual search that little cognitive capacity remains for processing writing explanations.

It should be noted that Mayer (2001, 2005a; Mayer & Moreno, 2003) considers the modality principle as a guideline to decrease intrinsic cognitive load. In this review we regard the modality principle primarily as a guideline to overcome the split-attention effects, typical for complex animated models, and so decrease extraneous load. However, we concur with Mayer that using spoken explanations instead of written explanations implies that more information can be processed through the visual channel. In this way more cognitive capacity becomes available for processing complex subject matter.

The fourth guideline pertains to the use of the contiguity principle. The contiguity principle states that verbal explanations accompanying pictorial material should be presented contiguously in time or space to overcome the split-attention effect. The rationale underlying the spatial contiguity principle is that visual search between for example, written explanations and pictorial information is reduced so that cognitive capacity is released for relevant learning activities (Mayer, 2005b). For temporal contiguity, the rationale is that both the explanation and the pictorial information are simultaneously held active in working memory which is a condition for integrating both information sources (Mayer, 2005b). In an animation about the formation of lightning, Mayer and Moreno (1999, Experiment 1) observed that learners who received written explanatory text that was close to the animation performed better on transfer than those who received text that was physically far away from the animation. Mayer and Sims (1994) compared concurrently and successively delivered spoken explanatory text that accompanied an animation. Learners who received the concurrent narrated animation performed better on transfer than learners who received the successive narrated animation. This result was confirmed by Mayer, Moreno, Boire, and Vagge (1999). The latter study also revealed that the temporal contiguity effect was eliminated when the successive narration was broken up in small parts that lasted only a few seconds. Apparently, the fast alternation between narration and animation enables the learners to make connections between the verbal and pictorial information without overloading the cognitive system. When the expert points to the runner on the stand in the 'running contest' animated model, the explanation that this competitor can not compete anymore for the silver medal must be spoken at the same time or, when written, the text should appear very close to the runner on the stand.

The fifth and last guideline is the application of signaling or cueing. According to Mayer and Moreno (2003) signaling is the provision of cues to the learner how to select and organize the instructional material (see also Mayer, 2005b). In this respect signaling covers a broad spectrum including stressing key words in a speech, organizing words in printed text by underlining them, and presenting images such as arrows to focus the attention to a particular part of an animation. This review focuses on visual cues that are used to prevent visual search. As stated earlier, understanding will only commence when the learners connects the verbal and pictorial information. With high visual search, learners unnecessarily use cognitive capacity for relating both information sources. Some studies report that visual cues fail in multimedia (Tabbers, Martens, & van Merriënboer, 2004), whereas others show that cueing can be effective when the amount of necessary visual search, such as in complex animations, is high (Jeung, Chandler, & Sweller, 1997). Mautone and Mayer (2001, Experiment 3) investigated the effect of signaling in a narrated animation and found that signaling was effective when both the animation and the narration were signaled (signaled words were spoken with a slower, deeper intonation), but not when neither the animation nor the narration was signaled. In another study, Craig, Gholson, and Driscoll (2002) failed to prove the effectiveness of a pedagogical agent with a signaling function. Possibly, the way that cueing was implemented in this study, namely, as rather global gestures in the direction of the location of the screen where the learner had to attend to, was not directive enough to serve the purpose of cueing and yield the desired effects. Imagine that one of the runners in the 'running contest' animated model has finished and has moved to the stand. In order to focus the attention of the learner on the parts of the animated model visualizing that this is a drawing without replacement, the pedagogical agent may point first to the runner on the stand and then point to the remaining runners (who start running again).

Guidelines for Increasing Germane Cognitive Load

Typically, learners view animated models passively. With respect to modeling, Bandura (1976) observed a stronger effect when learners engage in active coding. Other researchers as well have advocated active learning (Chi et al., 1989; Mayer, 2001; Wittrock, 1974). The generation of self-explanations has proven to be a successful approach in order to engage in active processing of learning material (Chi et al., 1989; Renkl, 1997; Renkl & Atkinson, 2002; Roy & Chi, 2005). By generating self-explanations learners integrate newly learned information with prior knowledge, which yields a more integrated knowledge base with increased accessibility, better recall, and higher transfer of learning (Chi, de Leeuw, Chiu, & LaVancher, 1994). Moreover, self-explaining forces learners to explicate their understanding and might help them to find out what they do and do not understand (Renkl & Atkinson, 2002). The assumption is that active processing will yield germane cognitive load. The following guidelines allow learners to engage in self-explanations when learning from animated models.

First, there is a broad group of guidelines that can be summarized as expectancy-driven instructional methods which enable learners to process instructional material more actively by predicting the next step in a process (Renkl, 1997). The focus of these guidelines is to help learners to construct or refine an initial schema. Hegarty et al. (2003) reported that learners who were prompted by questions to predict how a device worked before the animation continued, comprehended the working of the device better than learners who received no prompts. Also Mayer et al. (2003, Experiment 3) gave learners a question before showing an animation about the working of an electric motor and told them that they had to answer the question after the instruction. Learners who received pre-questions scored better on transfer than learners who did not receive pre-questions. Furthermore, Renkl (1997) found learners successful in solving problems in the domain of probability calculation when they engaged in anticipative reasoning. In anticipative reasoning learners first think about the next step in a task, for example in the solution process of a problem, and compare their understanding with the feedback provided by the learning environment before proceeding with the next step. To conclude, in a study in the field of biology, Moreno et al. (2001, Experiment 3) had learners design a plant, that is, determine the characteristics of leaves, root etc. and relate these to environmental features, such as rainfall. Learners who participated in the design of a plant before they listened to a spoken instruction, scored better on the more difficult transfer problems than learners who only had to listen to the spoken instruction. In the 'running contest' animated model, the learner can be prompted to answer the question 'Is this a problem with or without replacement?' just before this question is discussed in the animated model. A textbox may appear to fill out the answer. Only after providing an answer the 'running contest' animated model will continue and explain that this is a drawing without replacement.

In conclusion, these studies indicate that inciting learners to actively anticipate the problem solving process (e.g., by a prequestion or having learners to predict the next step in a process) is an effective instructional method that enables learners to engage in relevant learning activities.

The second guideline, subgoaling, seems especially useful for novices who can easily be overwhelmed by a complete solution process as they do not know which elements in the process of solving a problem belong together. In subgoaling, learners are prompted to group coherent steps in a procedure into one meaningful subgoal. Subgoals can facilitate learners to solve novel problems by helping them to identify which parts of a previously learned solution procedure need to be modified in order to solve a novel problem (Catrambone, 1996, 1998). Cues, such as labels or visual markers, can support learners in creating subgoals and thus encourage a learner to self-explain the purpose of the steps. Take for example the situation in which a problem on gravity has to be solved. Without subgoals several steps might be presented that learners have to pass through in order to solve the problem. However, the learners are not encouraged to explain why some of these steps belong together. With subgoaling the first subgoal could be a bold face text in which the learners are asked to identify the forces that act on an object. It is likely that learners have to identify the 'forces that act on an object' in other gravity problems as well, but that the way to achieve this subgoal might be different. Subgoaling is closely related to segmentation. A segment indicates a coherent part within a process or event and in this respect functions as a cue that might enable learners to create a subgoal for that segment. Imagine that the 'running contest' animated model is segmented. At the end of the segment in which it is concluded whether it is a drawing with or without replacement, learners can be prompted to formulate a subgoal by asking them: 'Which factor(s) in this problem determine whether it is a drawing with or without replacement?'. In this case the learner has two cues for formulating the subgoal: The question and the segmentation.

The third guideline, imagination, is derived from studies involving motor skills which have shown that imagining these skills before actually performing them leads to better results compared with not imagining these skills before performing them (Cooper, Tindall-Ford, Chandler, & Sweller, 2001). Contrary to the expectancy-driven methods that focus on the acquisition of an initial schema, the major effect of imagination is the facilitation of schema automation (although imagination may facilitate schema construction). By imagination an existing schema can be rehearsed and further automated. As automated schemas can be performed without placing a load on working memory, imagination releases cognitive resources that can be used for other aspects of (learning) the task. Stimulating learners to imagine procedures and concepts can be an effective guideline for the more advanced or proficient learners, because imagination is only possible if a schema that can guide behavior has already been acquired. For example, learners who had to imagine the procedure to construct formulas in a spreadsheet outperformed learners who only had to study this procedure both in the number of correct solutions and the solution times (Cooper et al., 2001). Leahy and Sweller (2004) confirmed these findings in another domain (interpreting contour maps and graphs about weather) with school teachers and young children. Furthermore, they found an interaction between imagination and split-attention, that is, learners who had to imagine after reading a graph with integrated explanatory labels performed better than learners who had to read a graph with the explanatory labels on a separate page. Apparently, split-attention required so much cognitive resource that little capacity remained for performing the imagination technique. More proficient learners first study the ‘running contest’ animated model. The animated model then disappears or the learners turn away from the screen. Subsequently, they are asked to imagine performing (and try to understand) the problem solving procedure shown before in the animated model.

The fourth guideline, using variability, focuses on the presentation of a sequence of tasks that differ in relevant features. The rationale behind the variability effect is that it encourages learners to identify and distinguish the relevant from the irrelevant features and by doing so develop appropriate schemas. For example, Quilici and Mayer (1996) exposed one group to a set of statistical word problems that varied in their structural features (e.g., the mathematical procedure that was needed to solve the problem), whereas another group was exposed to a set that varied only in surface features (e.g., the story line of the problem). On a transfer test, the group exposed to variability in structural features outperformed the group that was exposed to surface features. Variability is closely connected to contextual interference, that is, training conditions in which certain contextual factors prohibit a quick and smooth mastery of the skills being trained (van Merriënboer, Schuurman, de Croock, & Paas, 2002). High contextual interference may be realized by presenting problems in a random order so that each successive problem requires learners to apply different knowledge and skills. This practice schedule enables them to compare the solutions of the problems and construct more general applicable schemas that can be used then in larger classes of problems. Although this might yield an increase in cognitive load and instruction time during the learning phase, it will generate higher transfer performance. For example, in the domain of computer numerically controlled machinery programming, Paas and van Merriënboer (1994) investigated the effects of problem format and variability. They compared a low- and a high-variability conventional condition in which conventional practice problems had to be solved with a low- and a high-variability worked example condition in which worked examples had to be studied. They found that learners who studied high variable worked examples scored better on transfer than learners who studied low variable worked examples. Moreover, they found that high variability was only effective (i.e., imposed germane cognitive load) in the worked-example condition, where the extraneous cognitive load was sufficiently low to allow learners to profit from increased variability. These findings have been confirmed in the domain of troubleshooting (de Croock, van Merriënboer, & Paas, 1998; van Merriënboer et al., 2002). An example of variability in the 'running contest' animated model is the introduction of another 'running contest' animated model, beside the original one, adapted in such a way that seven runners start, but that one of the runners drops out after the first runner has finished. This adaptation varies the animated model in a structural feature, because it changes the method that can be used to solve the problem. The original 'running contest' animated model can be solved by counting all possible combinations of runners winning a golden, silver or bronze medal with a particular formula (i.e., the permutation formula). Eventually only one of these combinations is the correct one. In the adapted version one of the runners drops out after the first runner has already finished, so that the permutation formula does not hold anymore and a new method has to be introduced. To conclude, the variability guideline is an effective instructional method provided that the extraneous cognitive load is sufficiently low. Moreover, the variability guideline may take more cognitive load during training, but yield higher post-test performance.

It should be noted that there is a close relationship between the different sources of cognitive load and the complexity of the animated models. For simple animated models sufficient cognitive capacity is available for an increase of germane cognitive load. With animated models of intermediate complexity, germane cognitive load can only be increased when cognitive capacity is released by decreasing extraneous cognitive load. For highly complex animated models, both extraneous and intrinsic cognitive load should be decreased and, if possible, germane load increased.

Factors Mediating the Effect of Design Guidelines

Some caution should be taken when applying the guidelines. Several studies have revealed factors that mediate the instructional effects of the design guidelines.

The first mediating factor is the prior knowledge of the learner. Recent research on cognitive load theory, for example, has proven that design guidelines that are beneficial for novice learners can be ineffective or even detrimental when applied to experts (Kalyuga, 2005; Kalyuga, Ayres, Chandler, & Sweller, 2003). Novices typically lack the cognitive schemas that may release working memory resources and enable the learner to process information effectively. In the case of novices, the application of the design guidelines can compensate for this lack of schemas. More experienced learners, however, already possess schemas to process information effectively and the guidelines may yield instruction that is less effective for them. If the guidelines are nevertheless used by the designer of the instruction, more experienced learners will try connecting and integrating both schema information from their memory and the information based on the instruction. As this is redundant information that they cannot ignore, it can yield high cognitive load or even cognitive overload. This moderating effect of the level of expertise is referred to as the expertise reversal effect (Kalyuga et al., 2003). For more experienced learners the pretraining guideline would be less effective as they already possess the necessary schemas and are not confronted with a heavy intrinsic cognitive load. With respect to the imagination guideline it is clear that this guideline is not appropriate for novice learners, as they do not have the necessary schemas (Cooper et al., 2001).

A second mediating factor is the spatial ability of learners. For example, Mayer and Sims (1994) observed that high spatial ability learners profited more from animations with concurrent narration than low spatial ability learners. They concluded that the latter had to devote so much cognitive resources in constructing a mental visual representation that little resources remained for making connections between the visual and verbal representations. The high spatial ability learners, on the contrary, were able to build a visual representation with much less mental effort and therefore could devote more cognitive resources to the connection of visual and verbal representations.

A third mediating factor comprises the motivational aspects of learners. According to Fisher and Ford (1998), the allocation of effort toward learning activities is driven by individual motivational processes, such as personal goals and interests, incentives, individual personality differences, and metacognitive knowledge. In this respect, the pattern of cognitive load, that is, the specification of what is extraneous cognitive load and what is germane cognitive load, is not only a matter of instructional design but is mediated by the learners' learning activities which in turn depend on the personal goals and interests of the learner (Gerjets & Scheiter, 2003). For example, evidence for the mediating role of motivation was provided by Holladay and Quinones (2003) who found that self-efficacy generality, that is, efficacy beliefs related to a specific task can be generalized to similar tasks, can be regarded as a mechanism to explain the relation between task variability and transfer performance. In a computer naval air defense simulation, the higher scores on far transfer could not be ascribed to the high variability tasks that learners engaged in, but to the higher self efficacy generality resulting from the high task variability. In other words, there was no direct relation between practice variability and far transfer when the effects of self-efficacy generality were taken away.

The last mediating factor to be discussed is age. One of the central findings in cognitive aging research is that the efficiency of working memory deteriorates with aging. Several explanations have been proposed to account for this decline (Paas, van Gerven, & Tabbers, 2005). To start with, the reduced working memory view suggests that elder people have reduced processing capacity that becomes particular relevant with complex cognitive tasks (Gilinsky & Judd, 1994; Salthouse, Mitchell, Skovronek, & Babcock, 1989). When tasks become more complex older adults tend to be slower than younger adults. A second view, the reduced processing speed view, argues that reduced processing speed is a central mechanism in the explanation of age differences in performance (Fisk & Warr, 1996; Salthouse, 1996). A third view contends that older people cannot suppress irrelevant or extraneous information to the same extent as do younger adults. According to this reduced inhibition view the extraneous information imposes more load on the cognitive system of older adults than that of younger adults. Finally, several studies report that older adults show reduced coordination and integration of information sources. In deductive reasoning, for example, Light, Zelinski, and Moore (1982) observed that older adults had difficulty in integrating information across several premises, although they could recognize the separate premises perfectly. Because the total cognitive capacity of older adults is smaller than that of younger adults, the application of guidelines based on cognitive load theory and presented in this review might be proportionally more effective. Paas, Camp, and Rikers (2001), investigated the effects of goal specifity on younger and elder learners. When they have to solve a problem with a specific goal novices typically rely on weak problem solving methods, such as working backward from the end goal (i.e., the problem solution) to sub goals, which imposes such a high level of extraneous cognitive load that little cognitive capacity remains for learning. When solving a problem without such a specific goal they cannot use weak problem solving methods and exert the cognitive capacity for learning. Paas et al. (2001) found that the absence of a specific goal had a larger beneficial effect on learning to solving maze problems for elderly learners than for younger learners. With respect to multimedia learning and age only little research has been conducted (for an overview see Paas et al., 2005). A study by van Gerven, Paas, van Merriënboer, Hendriks, and Schmidt (2003) revealed no proportional greater modality effect with older adults, although elder learners reported less cognitive load and needed less training time than younger learners when they studied multimodal materials (visuals and spoken text) rather than unimodal materials (visuals and written text).

Conclusion and Discussion

In the previous sections it has been argued that recent developments in information technology have enabled the application of animations and pedagogical agents with respect to cognitive modeling. Cognitive modeling deals with cognitive processes that are not directly observable. In order to make this possible, the cognitive processes of the model have to be externalized. As animations are transient they fit the dynamic nature of modeling. Moreover, animations can facilitate the externalization of the cognitive processes, especially when they are difficult to describe in words. Animated pedagogical agents can stimulate the learner to invest more effort to understand the model performance depicted in the animation and give specific support to the learner. It was also argued that the application of animations could pose substantial extraneous cognitive load on the learner's cognitive resources because information is dispersed both sequentially and simultaneously. According to the current focus of cognitive load theory, extraneous cognitive load should always be minimized; if this is insufficient to prevent cognitive overload, intrinsic cognitive load may be decreased as well, and at the same time, germane cognitive load is increased within the limits of totally available cognitive capacity. Therefore, three sets of guidelines were presented. First, guidelines were discussed that can decrease intrinsic cognitive load, such as the presentation of a range of tasks in a simple-to-complex sequence and pretraining. Second, guidelines were proposed that can decrease extraneous cognitive load, such as the implementation of pacing, segmentation, the modality effect, the contiguity effect, and signaling. Third, guidelines were discussed that stimulate germane cognitive load, such as the implementation of expectancy-driven instructional methods, subgoaling, imagination, and variability.

It was also emphasized that the effectiveness of these guidelines depends on several mediating factors, such as, prior knowledge, spatial ability, motivation, and age of the learner. Figure 2 shows an integrative framework for the design of animated models based on a model by van Gerven et al. (2003). In the figure the guidelines are located near the type of cognitive load that they influence. The rectangle with 'Available cognitive capacity' is put in the center of the figure to indicate that optimizing animated models implies that the cognitive capacity has to be increased. In order to increase the available cognitive capacity, designers may decrease extraneous cognitive load (e.g., by using the contiguity guideline) and, if necessary, decrease intrinsic cognitive load (e.g., by using the sequence of simple-to-complex whole tasks). However, the available cognitive capacity, can be increased or decreased (depicted by the +/- symbol) by moderating factors, such as, spatial ability. For example, learners with high spatial ability may have more cognitive capacity available when learning from animated models than learners with low spatial ability, because they need less cognitive resources to construct a visual representation. The 'Available cognitive capacity' and 'Germane cognitive load' rectangles are overlapping to indicate that sufficient cognitive capacity is only a requisite for germane cognitive load. It does not guarantee that learners will engage in relevant learning activities that impose germane cognitive load. In most cases they will have to be incited to do so by applying design guidelines, such as expectancy driven methods. Furthermore, Figure 2 makes clear that an increase in germane cognitive load will increase performance in measures such as transfer and retention.

This review summarized and evaluated guidelines that can be useful for animated models, that is, the use of animations in conjunction with a supportive pedagogical agent in modeling problem-solving processes. However, as stated in this review, animations are not always more effective than static visualizations. It is also clear that the creation of animations can be labor-intensive and expensive. Therefore, instructional designers should carefully consider whether animated models or static visualizations are most appropriate for the skills and knowledge that have to be learned. The review also gave rise to some issues that justify a systematic research on animated models and the most appropriate guidelines to be used. First, researchers have focused on different kinds of domains. Most research is conducted with cause-and-effect systems, such as the origin of lightning (Mayer

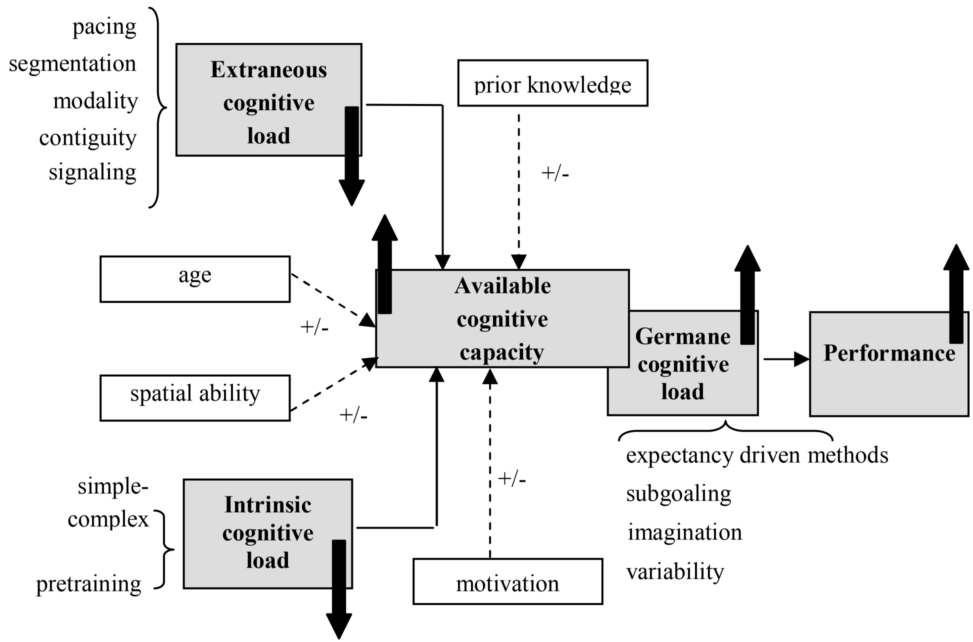

Figure 2. *An integrative framework for the design of animated models. Grey rectangles represent dependent variables. White rectangles with discontinuous arrows represent moderating factors. Continuous arrows represent causal relations.*

& Chandler, 2001) and the working of devices (Hegarty et al., 2003). But researchers also studied the modeling of procedural tasks, such as performing a first-aid task (Michas & Berry, 2000) and tying nautical knots (Schwan & Riempp, 2004). Cause-and-effect systems involve knowledge about its components and knowledge about the behavior of these components. The two-phase approach which is put forward as a method to decrease intrinsic cognitive load is appropriate in this case, but less for sequentially oriented events with a strong procedural orientation, such as performing a first-aid task. In the latter case a simple-to-complex whole-task sequencing approach seems more appropriate. Second, this review has shown that the design guidelines might interact, such as the interaction between modality and pacing (Tabbers et al., 2002), problem format and variability (Paas & van Merriënboer, 1994) or imagination and spatial contiguity (Leahy & Sweller, 2004). This indicates that the design guidelines can be further qualified when these interactions are taken into account. Third, combinations of guidelines, such as the signaling and modality guideline, might be particular effective. The pedagogical agent in an animated model might be used to cue the learners' attention to the relevant part in the animation and meanwhile provide auditory explanatory information. Fourth, no research has been conducted on the relationships between the guidelines in large training programs. Especially for complex domains, such as learning to maintain computers, training programs are relevant. An interesting avenue for future research is to investigate whether the effect of guidelines in animated models in the context of such training programs is different from applying the guideline to a single animated model. In a training program for computer maintenance, for example, both a sequence of simple-to-complex whole tasks and segmentation can be applied. For computer maintenance, the simplest task might deal with only one obvious computer problem that has to be solved, whereas in the most complex task several interrelated problems might occur. In the training program each task might be first presented with an animated model, showing an expert explaining how a problem is solved followed by a similar task that learners have to perform themselves with a real computer. Whereas a sequence of simple-to-complex whole tasks is used to decrease intrinsic cognitive load, the segmentation guideline for decreasing extraneous cognitive load can be applied for the separate animated models. It would be interesting to know whether segmentation in animated models that are part of a training program will yield different effects compared with segmentation applied to isolated animated models. In order to design instructionally effective animated models and to develop a comprehensive design theory for learning from animated models, a thorough and systematic research program is required. In particular this research program should investigate under which conditions particular animated models may be effective or not, that is, it should not only consider the guidelines and the mediating factors, but it should also take into account the four issues mentioned above. For example, this review proposed to apply the modality principle (i.e., use spoken explanations instead of written explanations) in order to decrease extraneous cognitive load. On the other hand, learner pacing seems to reverse the advantage of spoken over written explanations. In this case the research program has to formulate clear research questions that unravel under which conditions the modality principle is effective in animated models and under which conditions it is not. The application of animated models meets two focal points of contemporary educational theory. First, animated models performing and showing how they deal with real-life problems can enable the implementation of authentic learning in a meaningful context. Second, the modeling of cognitive processes with animated models is in line with the current focus on lifelong learning and problem-solving skills. From this perspective, animated models can be a promising instructional approach, provided that a balanced set of guidelines, based on the aforementioned comprehensive design theory, is applied in order to assure an optimal use of cognitive resources.

Chapter 3 - Observational Learning from Animated Models: The Relation between Pacing, Structure, and Modality

Abstract

In the domain of probability calculation, two 2 x 2 factorial experiments investigate the relation between pacing (learner vs. computer paced) and structure (segmented vs. continuous) in animated models, either with spoken (Experiment 1, $N = 60$) or written (Experiment 2, $N = 78$) explanations. The experiments reveal that with spoken explanations, learner paced continuous and computer paced segmented animated models yield higher near transfer performance than learner paced segmented animated models. With written explanations, learner paced continuous animated models lead to higher far transfer performance than learner paced segmented and computer paced continuous animated models. We argue that the characteristic of written explanations to read strategically (scan, reread text) enables learners to construct more elaborated schemas that facilitate near transfer performance regardless of the pacing and structure guidelines. Moreover, we contend that effective learner pacing is only to occur when the expected level of control corresponds with the given level of control, and when the control concerns the continuous animated model rather than its segments.

Modern educational theories advocate the application of modeling in learning environments that focus on authentic tasks (Collins, Brown, & Newman, 1989; van Merriënboer, 1997). Traditionally, modeling has been associated with the observable, behavioral performance of an expert, such as in action-oriented tasks like sports, writing, and assembling machines (Kitsantas, Zimmerman, & Cleary, 2000; Zimmerman & Kitsantas, 2002). However, the current focus on lifelong learning and flexibility in task performance emphasizes the modeling of cognitive skills, such as problem solving and reasoning in a variety of domains (Jonassen, 1999; van Merriënboer & Kirschner, 2007). This type of modeling, commonly referred to as cognitive modeling, concerns covert cognitive processes that have to be explicated in order to become observable to a learner. It is believed that cognitive modeling can foster understanding by showing not only what is happening, but also why it is happening (Collins, 1991; van Gog, Paas, & van Merriënboer, 2004). In the last two decades, computer-based animations with verbal explanations are increasingly used to explicate the covert cognitive processes in cognitive modeling (Casey, 1996; Chee, 1995; Collins, 1991), especially for more abstract procedures and problem-solving processes. Furthermore, developments in computer technology have facilitated the authoring and the application of pedagogical agents, that is, computer-based characters that support learners with feedback and guidance in order to engage them in more active learning (Clarebout, Elen, Johnson, & Shaw, 2002).

We refer to the combined use of animations with explanatory text and pedagogical agents in modeling as animated models. These animated models illustrate the solving of problems such as scientific problems (e.g., solving a problem about gravity), mathematical problems (e.g., probability calculation problems), or search problems (finding information on the Internet). The pedagogical agent functions as a social model and guides the learner through the animation, for example, by moving around the screen and guiding the learner's attention to specific parts of the animation, by addressing the learner in a personalized style and/or by showing which errors typically may occur and how they may be avoided by the learner. For example, in solving a problem in the domain of probability calculation, it is important to know whether it is a 'drawing with or without replacement'. For novices this concept may be rather abstract and difficult to understand. An animation can visualize the concept by showing what is happening, for instance, in a situation with mobiles. Imagine a mobile factory where in an assembly line six mobiles -each with a distinct color- are packed in a box. A controller blindly selects two mobiles to check them for deficiencies. The learner has to calculate the probability that the controller draws a yellow and a blue mobile from the box. The animated model may show a box with six mobiles. The first mobile that is drawn from the box can be put away from the box. As is shown in Figure 1, the pedagogical agent may move to the drawn mobile and explain that a mobile that is drawn should not be put back because you do not want to draw an already checked mobile again. Then the group of remaining mobiles in the box becomes encircled. The pedagogical agent moves to the box with mobiles and explains that the second mobile will be selected from the remaining mobiles.

Also the way information is presented can impose a cognitive load. This load can hinder learning, that is, reflect extraneous cognitive load, or enhance learning, that is, reflect germane cognitive load. The latter type of load can result from cognitive activities, such as elaboration and abstraction, which are important for the construction and automation of cognitive schemas. From an instructional design point of view, especially extraneous cognitive load and germane cognitive load should be considered as communicating vessels, as the reduction of extraneous cognitive load can free cognitive resources that can be used for activities that impose a germane cognitive load.

Figure 1. Screen shot of the 'Checking mobiles' animated model which displays and explains why this is a 'drawing without replacement'.

Within cognitive load research the split-attention effect, which occurs when two or more mutually referring sources of information must be mentally integrated in order to derive meaning from subject matter, is one of the most investigated phenomena causing extraneous cognitive load (see for a review, Sweller et al., 1998). A spatial split-attention effect may occur when learners have to observe a complex animated model and simultaneously have to read an explanation. Moreover, a more specific split-attention effect is caused by the transient nature of the information in an animated model which implies that once a part of the information is missed or only partly processed, the remaining parts may become incomprehensible. This is especially relevant for novice learners who lack the prior knowledge to attend to relevant aspects of the animated model and may easily get lost in the continuous stream of transient information (Hinds, Patterson, & Pfeffer, 2001). From a cognitive load perspective this means that novices will often use cognitive resources inadequately, for instance by attending to the most salient features of an animated model that are not necessarily the most relevant ones for understanding the animated process (Hegarty, Kriz, & Cate, 2003; Lowe, 2003).

Table 1. Outline of conditions involved in pacing studies. For each study the condition(s) involved are indicated with the X sign, the condition(s) that performed best on transfer performance are marked with an underlined X

	LP Segments	CP Continuous	LP Continuous	CP Segments
Boucheix & Guignard (2005)	X	X		
Hasler, Kersten, & Sweller (in press)	X	X	<u>X</u>	
Mayer & Chandler (2001)	X	X		
Mayer, Dow, & Mayer (2003)	X	X		
Moreno & Valdez (2005)	X			X
Schwan & Riempp (2004)		X	<u>X</u>	

Note: LP = Learner pacing, CP = Computer pacing

The present study investigates how pacing, structure and modality can be used to control these split-attention effects. Pacing involves the control over the continuation of the presentation of instructional material, which can be exerted either by the learner or the system (e.g., a computer). Learner pacing may enable learners to adapt the presentation of multimedia instructional material to their cognitive needs (e.g., by pausing the instruction or going backward in the material). The structure of multimedia instruction can be either a continuous flow of information or information split up in a series of discrete segments that correspond to meaningful parts of the demonstrated process, and that can be activated sequentially (i.e., one by one) or in any desired order. Segmentation may enable learners to spend less effort in order to discern the important aspects of the problem-solving process. In this way cognitive resources are released that can then be used for more relevant learning activities such as schema construction and automation. Table 1 presents an outline of multimedia studies in which pacing and structure were investigated.

The majority of these studies compared a learner paced segmented version of an animation with a computer paced continuous version in a variety of domains and found the learner paced segmented condition to be most effective in terms of transfer performance (Boucheix & Guignard, 2005; Mayer & Chandler, 2001; Mayer, Dow, & Mayer, 2003). Moreno and Valdez (2005), on the other hand, compared a learner paced segmented version in which students had to put segments in the right order with a version in which the computer put the segments in the right order, but found no differences between the two conditions. Conversely, Schwan and Riempp (2004) compared a learner paced and a computer paced continuous video on nautical tie knotting and reported that the former group performed better in terms of practice time in order to reproduce the knots correctly. Finally, Hasler, Kersten, and Sweller (in press) investigated the presentation of the causes of day and night in four conditions: A learner paced segmented animation, a learner paced continuous animation with a stop and play option, a computer paced continuous animation, and a computer paced narrated-only presentation. The results of this study indicate that both learner paced groups performed better than the two computer paced groups on a test with high element interactivity. It is difficult to derive design guidelines for pacing from these findings since they involved different combinations of learner vs. computer pacing and segmented vs. continuous animations. For example, the effect of computer pacing and segmentation was investigated in only one of the studies. Therefore, one of the objectives of this study is to further explore the relationship between pacing and the structure of information.

Visual material in multimedia instruction can be accompanied by spoken or written explanations. The term modality refers to the auditory (spoken) or visual (written) sensory mode in which explanations are presented. Research has shown the superiority of spoken explanations over written explanations, in particular when complex visual learning material is involved (Atkinson, 2002; Moreno & Mayer, 1999; Mousavi, Low, & Sweller, 1995; Sweller et al., 1998; see for a review, Ginns, 2005). This is called the modality effect. The modality effect assumes that working memory comprises a verbal system in which verbal information is processed, as well as a visual system in which pictorial information is processed. The combined use of the visual system for pictorial learning material and the verbal system for the spoken explanation of this material increases effective working memory capacity and so facilitates learning (Mousavi et al., 1995).

To investigate the relation between pacing and structure (as a function of modality) two explorative studies were conducted in the domain of probability calculation. Experiment 1 investigates the relation between pacing and structure with spoken explanations, and Experiment 2 investigates the relation between pacing and structure with written explanations.

Experiment 1

Method

Participants and Design

Experiment 1 used a 2 x 2 factorial design with the factors pacing (learner pacing vs. computer pacing) and structure (segmented animated model vs. continuous animated model). Participants were 62 students of pre-university education in the Netherlands, who were randomly assigned to the experimental conditions. The data of two students in the condition with learner pacing and segmented models had to be removed because of technical problems with the computer so that 60 participants remained (31 females and 29 males). This resulted in 13 participants in the condition with learner pacing and segmented models, 17 participants in the condition with computer pacing and segmented models, 15 participants in the condition with learner pacing and continuous models, and 15 participants in the condition with computer pacing and continuous models. Their mean age was 15.8 years (*SD* = .89). Participants were not paid for their collaboration but their participation in the experiment yielded credits for extra school activities.

Materials

The computer-based learning environment was developed with Flash MX. The computer-based learning environment consisted of the following parts: A demographic questionnaire, a prior-knowledge test, an instructional component and an assessment component. All parts were user timed, that is, the participants could decide how much time they spent on each part.

Demographic questionnaire. The experiment started with a demographic questionnaire in which information was asked about gender, age, the profile of their study and the mathematics subjects they engaged in and the difficulty level of these mathematics subjects.

Prior-knowledge test. The prior knowledge test that followed the demographic questionnaire consisted of 8 open questions and 4 multiple choice questions of varying difficulty. An example of an open question is:

> 'You are playing a game with some friends and it is your turn to throw a dice. If you throw sixes you win. What is the probability that you throw sixes?'

An example of a multiple choice question is:

> 'You have a deck of cards from which you select 4 cards. You want to get an ace, king, queen and jack in this specific order. Does it matter whether you put back the selected cards before each new selection or not?
>
> a. Yes, your chances increase when you put back the selected cards
> b. Yes, your chances decrease when you put back the selected cards
> c. No, your chances remain the same whether you put back the selected cards or not
> d. This depends on the number of jokers in the deck of cards'

Instructional component. The instructional component consisted of an introduction to probability calculation and the experimental treatment. The introduction comprised a brief explanation of concepts in probability calculation, such as randomization, individual events, complex events, and how counting can be used in calculating the probability. After this introduction, which was identical for all four groups, participants received condition-specific information about the learning environment. With a continue button the participant could start the experimental treatment which consisted of eight animated models demonstrating and explaining how to solve a particular probability problem. An example of such a problem is

> 'In a factory mobile phones are produced. On a production line the mobiles receive a cover in one of six colors before they are packed in a box. Each box contains six mobiles in the colors red, black, blue, yellow, green, and pink. Before a box leaves the factory two mobiles are selected randomly and checked on deficiencies. What is the probability that you select the yellow and the blue mobile from one box?'

The animated models were grouped in four problem categories which resulted from two important characteristics in probability calculation: The order of drawing (relevant vs. irrelevant) and replacement of drawing (without replacement vs. with replacement). For each problem category two animated models were presented to enable learners to recognize structural similarities and dissimilarities between problems and thus learn not only how to solve problems but also when to apply which procedure. Table 2 shows the order in which the animated models were presented.

Table 2. Order in which the animated models are presented and the distribution across the problem categories

Order of presentation	Context of animated model	Problem category
1	Mountainbike trip with your friend[1)]	Order relevant / without replacement
2	Running contest	
3	Mountainbike trip with your friend[1)]	Order relevant / with replacement
4	PIN code	
5	Mountainbike trip with your friend[1)]	Order irrelevant / without replacement
6	Checking mobiles in a factory	
7	Mountainbike trip with your friend[1)]	Order irrelevant / with replacement
8	Finding figures in a cereal box	

Note: 1) Animated models 1, 3, 5, and 7 share the same context. The problems that have to be solved are different.

In the animated models the problems were solved by one of two possible methods. The method of individual events was applied in four animated models. It implies that, first, the probability of individual events is calculated separately and, subsequently, the complex event is calculated by multiplying the individual events. For example, in the “checking mobiles in a factory” problem, first the probability of selecting the yellow and the blue mobiles was calculated (respectively 2/6 and 1/5) and these two probabilities were subsequently multiplied for calculating the probability of the complex event. The method of counting was applied in the four other animated models. This method implies that all possible combinations are balanced by the correct number of combinations. For example, suppose someone calculates the probability to guess a PIN code consisting of 4 figures. For each figure 10 different numbers (0 up to and including 9) can be chosen, whereas for 4 figures 10*10*10*10, that is, 10,000 possible combinations can be chosen of which only one combination is correct.

The segmentation implied that the animated model was divided into a series of segments in which each segment corresponded with one step in the solution procedure. The length of the segments and the moment of segmentation were determined in consultation with three experts (one statistician and two teachers in mathematics). Finally, the segments were tested and slightly revised after a pilot with 15 participants. The number of segments depended on the method that was used for solving the problems. The first three segments, however, were always the same: (1) defining the context of the animated model (2) determine whether the order of drawing is important or not and (3) determine whether it is a drawing with or without replacement. In segment 4 the method of solving the problem was determined. When the method of counting was used, two more segments were identified: (5) selecting the formula, and (6) calculating the probability. In the case of individual events, segment 4 was continued with the first individual event. The next segments comprised the other individual events. In the last segment the complex event was calculated. Figure 2 shows the beginning of the segments of the mobile phone animated model.

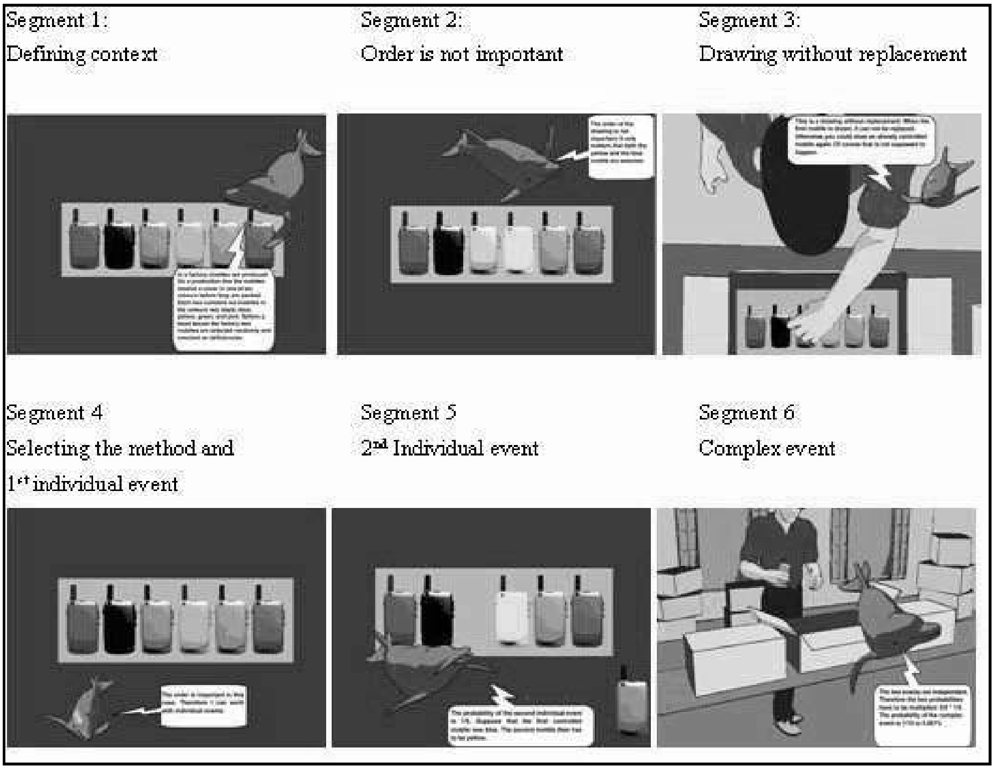

Figure 2. Segmentation in the mobile phone animation.

In the learner paced-segmentation condition the animated model started automatically. At the end of a segment, the participants had to press the play button to start the next segment. In addition, they could pause and continue the animated model at any moment during a segment. The participants in this condition also had the opportunity to skip backward and forward to segments. Each animated model was completed with supportive, spoken explanations by a pedagogical agent that was implemented as a dolphin. The spoken explanations of the pedagogical agent were provided by a male voice without accent. In each model the pedagogical agent demonstrated one of two possible problem-solving processes. The pedagogical agent explicated which considerations underlie the choice of one of the two methods for solving the problem. The computer paced-segmentation condition was identical to the learner paced-segmentation condition with the exception that the participants could not pause or continue the animated model neither could they skip forward or backward to segments. At the end of a segment the animated model paused for 3 seconds and then continued automatically. The learner paced-continuous condition was identical to the learner paced-segmentation condition with the exception that the animated model was not divided in segments. Participants were allowed to pause and to continue the animated model at any moment. Moreover, they were allowed to restart the animated model. The computer paced-continuous condition was identical to the learner paced-continuous condition with the exception that participant were not allowed to pause, continue or restart the animated model.

In all conditions, after each animated model, the participants were asked to score the mental effort they perceived when they studied the animated model on a one-item 9-point rating scale based on Paas (1992; see also Paas et al., 2003). This scale ranged from ‘very, very little effort’ to ‘very, very much effort’.

Assessment component. After the instructional component with the eight animated models an assessment component followed consisting of twelve transfer tasks. Of the twelve tasks, eight tasks were near transfer tasks. The near transfer items were analogous to the problems that were solved in the animated models. The following is an example of a near transfer task:

> ‘In a pop music magazine you see an ad under the heading FOR SALE in which a ticket for a spectacular concert by your favorite pop group is offered. Unfortunately the last 2 digits of the telephone number, where you can obtain information about the ticket, are not readable anymore. You really like to have the ticket and decide to choose the 2 digits randomly. What is the probability that you dial the correct digits on your first trial?’

The remaining four items were far transfer items. These far transfer items were different from the problems solved in the animated models. Take for instance the following example of a far transfer task:

> ‘In order to determine the final mark for a subject your teacher uses two complementary methods. First, you have to perform a practice task,

followed by a test consisting of 8 multiple-choice questions. One out of five possible practice tasks (named A, B, C, D and E) is randomly assigned to you. You know you have done practice on task E a month ago. For the multiple choice questions your teacher uses a large pool of 100 different multiple-choice questions from which he randomly selects 8 questions for you. Also in this respect you have made a test before with 8 questions from this pool. What is the probability that you are assigned practice task E as well as the 8 questions you have had before?'

This far transfer task comprises a problem from a specific problem category, that is, order is not important and without replacement (the drawing of the multiple choice items), which has to be combined with one individual event (the practice task).

After each transfer task the participants were asked to score the mental effort they perceived when they solved the transfer task on a one-item 9-point rating scale based on Paas (1992; see also Paas et al., 2003). This scale ranged from 'very, very little effort' to 'very, very much effort'.

Procedure

The experiment was conducted in one session and was run in the computer rooms of the participating schools. Each computer had a headset to listen to the verbal explanations. After welcoming the participants, the experimenter gave them a code to log in on the computer based learning environment. When the participants entered the environment, on the computer screen the purpose of the experiment was explained and an outline was given of the different parts of the experiment. First, participants had to fill out a demographic questionnaire on the computer. Then, the prior knowledge test was conducted. The instruction phase started after the prior knowledge test with the brief introduction to probability calculation. After reading the introduction they could press a continue button to study the animated models. After each animated model, participants were asked to score their perceived mental effort. By pressing a button they could proceed to the next animated model. After the instruction phase a transfer test was administered. Participants could use a calculator as well as scrap paper during the transfer test. All input to the calculator was logged and the scrap paper was collected after the experiment. After each transfer item they were asked to score their invested mental effort. Finally, the participants were debriefed and thanked for their participation.

Scoring

For each open question of the prior knowledge test a list of correct answers was formulated. For each correct answer 1 point was assigned, otherwise 0 points. Computational errors were ignored and no partial credits were awarded. For each correct multiple-choice question participants received 1 point, otherwise they received 0 points. In total the maximum score on the prior-knowledge test could be 12 points. The mental effort scores that were administered after each animated model were summed across all eight animated models and divided by 8, resulting in an average score on mental effort ranging from 1 to 9. For each near and far transfer task a list of correct answers was formulated. Computational errors were ignored and no partial credits were awarded. Each near and far transfer item was assigned 1 point when it was correct and 0 points when it was incorrect. The maximum for the near transfer task was therefore 8 points, for the far transfer task this was 4 points. The mental effort scores after solving the near and far transfer tasks were summed across the eight near and the four far transfer tasks and divided by respectively eight and four, resulting in an average scores on mental effort on near and far transfer ranging from 1 to 9. Instruction time (in s) was defined as the time that the participants needed for the introduction (the basic theory of probability calculation) and the instruction component (the time spent on observing the animated models). The time (in s) needed to accomplish the transfer tasks was logged by the computer. The computer logged both the start time and the end time of the instruction.

Results

The dependent variables under investigation were instruction time (in s), mental effort during instruction (score 1-9), performance on near transfer (score 0-8), performance on far transfer (score 0-4), mental effort on near transfer (score 1-9), mental effort on far transfer (score 1-9), time on near transfer tasks (in s), and time on far transfer tasks (in s). For all statistical tests a significance level of .05 was applied. Effect sizes are expressed in terms of omega-squared (w^2). Table 3 shows the mean scores and standard deviations of the dependent variables for all conditions.

We began our analysis with testing the measures that could be used as covariates for further analyses. First, the ANOVA performed on prior knowledge revealed a main effect for pacing, $F(1, 56) = 4.50$, $MSE = 3.32$, $p = .038$, $w^2 = 6\%$, indicating that learners in the learner paced condition possessed more prior

Table 3. Mean scores and standard deviations on prior knowledge test and dependent variables for all conditions with spoken explanations

	Learner pacing						Computer pacing					
	Segmented			Continuous			Segmented			Continuous		
	M	SD	AM	M	SD	AM	M	SD	AM	M	SD	AM
Prior knowledge test (0 -12)	6.00	1.68		6.53	1.59		5.05	2.30		5.46	1.50	
Instruction												
Instruction time (s)	1,917	485		1,560	138		1,769	224		1,653	265	
Mental effort during instruction (1-9)	2.00	1.10	2.01	2.10	1.52	2.37	2.32	1.33	2.13	2.51	1.98	2.48
Transfer Test												
Performance on near transfer (0-8)	2.61	1.19	2.61*	4.40	2.19	3.94*	3.70	1.86	4.11*	3.20	1.56	3.26
Performance on far transfer (0-4)	.38	.50	.39	.53	.91	.34	.64	.70	.77	.60	.98	.62
Mental effort on near transfer (1-9)	4.69	1.83	4.65	3.67	1.34	3.80	4.60	1.93	4.73	4.65	2.17	4.65
Mental effort on far transfer (1-9)	5.73	1.69	5.49	4.89	1.74	5.12	5.37	1.90	5.53	5.82	1.44	5.87
Time on near transfer tasks (s)	481	175		458	161		540	211		524	242	
Time on far transfer tasks (s)	350	168		362	81		390	180		455	232	

Note: AM means adjusted means. Scores with * differ statistically (i.e., learner pacing continuous and computer pacing segmented perform significantly better than learner pacing segmented).

knowledge than learners in the computer paced condition (*M* = 6.28 and *SD* = 1.69 vs. *M* = 5.25 and *SD* = 1.95). Next, an ANOVA with regard to instruction time showed a main effect for structure, $F(1, 56) = 9.32$, $MSE = 87{,}910.36$, $p = .003$, $w^2 = 12\%$), indicating that learners in the segmented conditions spent more time on instruction than learners in the continuous condition (*M* = 1835 and *SD* = 365 vs. *M* = 1606 and *SD* = 213). All tests for homogeneity of regression were found to be nonsignificant, $F < 1.3$. Therefore, data were analyzed with 2 (Pacing: learner vs. computer) by 2 (Structure: segmented vs. continuous) analyses of variance with prior knowledge and instruction time as covariates (ANCOVAs).

No effect could be observed for pacing on performance on near transfer ($F(1, 56) < 1$, *ns*) and far transfer ($F(1, 56) = 2.51$, $MSE = .56$, *ns*), and no effect was found for structure on performance on near transfer ($F(1, 56) < 1$, *ns*) and far transfer ($F(1, 56) < 1$, *ns*). However, as Figure 2 shows, an interaction was found between pacing and structure on performance on near transfer, $F(1, 56) = 6.43$, $MSE = 2.59$, $p = .014$, $w^2 = 7\%$.

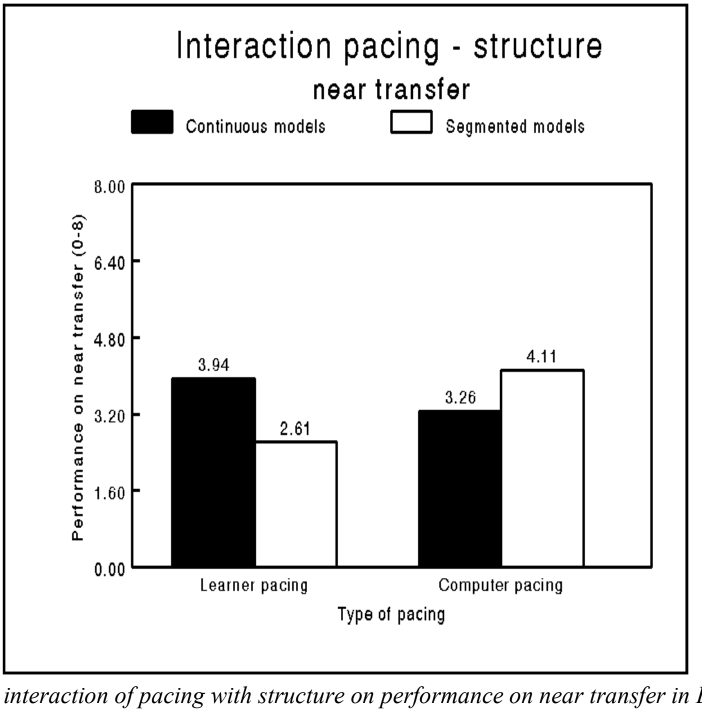

Figure 2. *The interaction of pacing with structure on performance on near transfer in Experiment 1.*

The interaction indicates that learner pacing yields higher performance on near transfer with continuous animated models (M = 4.40, SD = 2.19 for continuous animated models vs. M = 2.61, SD = 1.19 for segmented animated models), whereas for computer pacing no difference was found on performance on near transfer between continuous (M = 3.20, SD = 1.56) and segmented animated models (M = 3.70, SD = 1.86). Post hoc multiple comparisons based on the adjusted marginal means were conducted using the LSD procedure. This analysis showed that both the learner paced continuous and the computer paced segmented condition performed better than the learner paced segmented condition on near transfer. No interaction between pacing and structure was found on far transfer ($F(1, 56) < 1$, *ns*).

Neither main effects for pacing and structure nor an pacing by structure interaction was found on mental effort during instruction, mental effort on near transfer, and mental effort on far transfer (all $F(1, 56) < 1$, *ns*). For pacing no effect was found on time on near transfer ($F(1, 56) = 1.73$, MSE = 39,535.16, *ns*) and time on far transfer ($F(1, 56) = 3.98$, MSE = 30,004.89, *ns*). For structure no effect was found on time on near transfer and time on far transfer (both $F(1, 56) < 1$, *ns*). No interaction between pacing and structure was found on time on near transfer and time on far transfer (both $F(1, 56) < 1$, *ns*).

Discussion

Learners in the learner paced continuous and computer paced segmented conditions performed better on near transfer tasks than learners in the learner paced segmented condition. The higher scores cannot be ascribed to spending more time on the near transfer tasks. In the Introduction it was argued that segmentation could support learners in discerning the important steps in the problem-solving process, whereas learner pacing would enable learners to control the onset of these segments. However, in this experiment this combination resulted in the lowest score on near transfer. Cognitive dissonance theory (CDT: Festinger, 1957) may provide an explanation for these findings. The theory argues that individuals seek consistency among their cognitions (i.e., beliefs, opinions, observations) and that a dissonance will occur in the case of a disconsistency between these cognitions. Moreover, some researchers have argued that this dissonance may undermine task performance (Elliot & Devine, 1994; Pallak & Pittman, 1972). Evidence that such dissonance may arouse feelings of discomfort is suggested by a study that investigated the effect of mental effort and controllability on cardiovascular and endocrine responses. Previous to the experiment all participants were told that they could control the intensity of a noise presented during the performance of a task. However, only the participants in the conditions with controllability were able to actually control the intensity of the noise. For participants who could not control the intensity of the noise, although they were told they could, higher activation was reported of the sympathetic nervous system (e.g., higher blood pressure) which is associated with stressing factors (Peters et al., 1998). The second principle of CDT contains that the dissonance can be eliminated by reducing the importance of the conflicting cognitions, by acquiring new cognitions or by removing the conflicting cognitions. Applied to this experiment, cognitive dissonance may have appeared when the expectations of learners regarding control (a belief) were not in line with the control they could actually exert (an observation). Although learners may have tried to reduce this dissonance, the learning environment provided little opportunity to do so. Consequently, this may have increased their cognitive dissonance. This argument particularly pertains to learners in the learner paced segmented condition who might have expected a high level of control over the instructional material, but found the material to be largely controlled by the fixed segmentation. In the other conditions the expected level of control was more or less aligned with the actually available level of control. Learners in the computer paced segmented condition probably did not expect control and had no control. The difference between learner pacing and computer pacing when segmentation was involved, indicates that not segmentation in itself posed a problem, but that its effectiveness depended on the type of pacing used. In the continuous conditions the expectation regarding the control over the instructional material was in line with the possibilities of the learner. In the learner paced continuous condition the learners probably expected a high level of control and they were indeed enabled to exert such control (i.e., they could segment the animated model themselves). In the computer paced continuous condition learners might not have expected a high level of control over the instructional material and indeed did not have such control. These results suggest that for near transfer tasks it is not the issue whether learners should exert control over the instructional material or not, but that their perception of possible control should not deviate (too much) from the control they can actually exert during instruction. The lack of similarity between expected and actual control may have caused frustration and hence influenced the processing of the information provided by the animated models.

The mental effort scores between the conditions did not differ. The mental effort measure that was used did not differentiate between mental effort due to the perceived difficulty of the subject matter, the presentation of the instructional material, or being engaged in relevant learning activities. Although the scores are rather low, it is possible that the effect of the varying instructional techniques, that is, pacing and structure on the perceived mental effort might have neutralized each other. For example, the learner paced segmented condition induced an increase in extraneous cognitive load, but not in germane cognitive load. On the other hand, in the learner paced continuous condition less extraneous cognitive load was induced, whereas the invested germane cognitive load might have increased. Although no differences between conditions were found in mental effort during the near (and far) transfer tasks, a tendency can be observed in favor of lower scores for the learner paced continuous condition suggesting that these learners required less cognitive resources to solve the near transfer tasks.

Experiment 2

The purpose of the second experiment was to investigate the relation between pacing and structure when explanations are provided in written rather than spoken format.

Method

Participants

Seventy-eight students of pre-university education in the Netherlands (33 females and 45 males) participated. Their mean age was 16 years (*SD* = .83). They were randomly assigned to one of the four conditions. This resulted in 18 participants in the condition with learner pacing and segmented models, 21 participants in the condition with computer pacing and segmented models, 19 participants in the condition with learner pacing and continuous models, and 20 participants in the condition with computer pacing and continuous models. The mean score on the prior knowledge test was 6.34 (SD = 2.10), indicating that the participants had some knowledge (the maximum score was 12) regarding the subject matter. The participants were not paid for their collaboration but received credits for extra school activities.

Design

The design of Experiment 1 was used.

Material, Measurement instruments, and Procedure

With exception of the explanation in the animated models, which was presented in written format, the materials were identical to those used in Experiment 1. In order to prevent spatial split-attention effects to occur, the written explanations were presented in a text balloon next to the pedagogical agent, very close to the part of the animated model it was referring to. Measurement instruments and procedures were identical to Experiment 1.

Results

Table 4 shows the mean scores and standard deviations on the dependent variables for all conditions. We began our analysis with testing the dependent measures that could be used as covariates for further analyses.

An ANOVA with the between-subject factors pacing and structure revealed no effects of pacing, structure, or their interaction on prior knowledge (all F (1, 74) < 1, ns). In addition, there was no effect on instruction time for pacing (F(1, 74) = 1.36, MSE = 221,364.76, ns), structure, and their interaction (both F(1, 74) < 1, ns).

The dependent variables under investigation and method of analysis were the same as in Experiment 1 with the exception that no covariates were used. No effect could be observed for pacing on performance on near transfer (F(1, 74) < 1, ns) and far transfer (F(1, 74) < 1, ns), and no effect of structure was found on performance on near transfer (F(1, 74) < 1, ns) and far transfer (F(1, 74) = 1.33, MSE = .93, ns).

Table 4. Mean scores and standard deviations on prior knowledge test and dependent variables for all conditions with written explanations

	Learner pacing				Computer pacing			
	Segmented		Continuous		Segmented		Continuous	
	M	SD	M	SD	M	SD	M	SD
Prior knowledge test (0-12)	6.27	2.42	6.42	2.61	6.47	1.72	6.20	1.76
Instruction								
Instruction time (s)	1,709	537	1,870	522	1,890	376	1,941	435
Mental effort during instruction (1-9)	2.06	1.16	2.05	1.18	2.20	1.77	2.15	1.76
Transfer Test								
Performance on near transfer (0-8)	3.94	2.12	4.05	2.22	3.80	1.80	3.40	1.90
Performance on far transfer (0-4)	.55*	.85	1.31*	1.10	.90	1.13	.65*	.67
Mental effort on near transfer (1-9)	4.46	1.84	4.60	1.73	4.65	2.15	4.41	1.81
Mental effort on far transfer (1-9)	5.60	1.89	5.79	1.29	5.70	1.78	5.16	1.42
Time on near transfer tasks (s)	54200	181	472	216	585	206	533	156
Time on far transfer tasks(s)	609	252	514	263	446	155	498	177

Note: Scores with * differ statistically (i.e., learner pacing continuous performs significantly better than computer pacing continuous and learner pacing segmented).

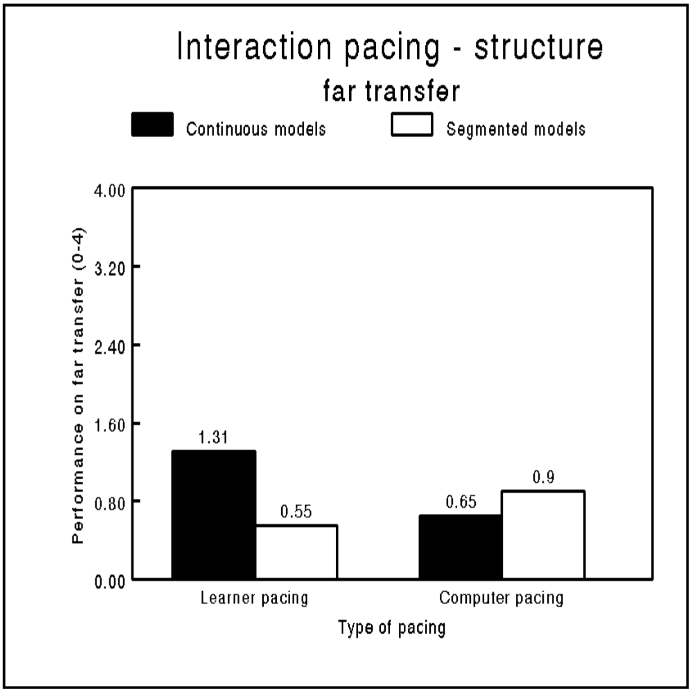

Figure 3. *The interaction of pacing with structure on performance on far transfer in Experiment 2.*

However, as Figure 3 shows, a significant interaction effect for pacing and structure was found on performance on far transfer performance, $F(1, 74) = 5.37$, $p = .023$, $w^2 = 8\%$. The interaction indicates that learner pacing yields higher performance on far transfer with continuous animated models ($M = 1.31$, $SD = 1.10$ for continuous animated models vs. $M = .55$, $SD = .85$ for segmented animated models), whereas for computer pacing no difference was found on performance on far transfer between continuous ($M = .65$, $SD = .67$) and segmented animated models ($M = .90$, $SD = 1.13$). Post hoc multiple comparisons based on the estimated marginal means were conducted using the LSD procedure. This analysis showed that the learner paced continuous condition performed better on far transfer than the computer paced continuous and the learner paced segmented condition. No interaction between pacing and structure was found on near transfer ($F(1, 74) < 1$, *ns*). Regarding mental effort during instruction, mental effort on near transfer, and mental effort on far transfer, no main effects for pacing and structure and neither an interaction between pacing and structure was found (all $F(1, 74) < 1$, *ns*).

Regarding the time on near transfer, no effect was found for pacing ($F(1, 74) = 1.32$, $MSE = 36{,}143.02$, *ns*), structure ($F(1, 74) = 1.79$, *ns*). Also the interaction between pacing and structure was not significant ($F(1, 74) < 1$, *ns*). Finally, no effect was found on time on far transfer for pacing ($F(1, 74) = 3.05$, $MSE = 46{,}439.82$, *ns*), structure ($F(1,74) < 1$, *ns*), and their interaction ($F(1,74) = 2.06$, *ns*).

Discussion

It was found that the learner paced continuous condition performed better on far transfer than the learner paced segmented and the computer paced continuous condition. This raises two questions. To start with, why are the differences found for far transfer and not for near transfer? Written explanations differ from spoken explanations because they enable learners to scan and reread words. In this way learners can select important words and organize them in cognitive schemas that are more elaborate and richer (i.e., they contain more information elements and relations between these elements) than those emanating from transient spoken explanations. This applies all the more to extensive explanations such as used in this experiment: The explanations not only contained words, but also numbers and sometimes fractions. The resulting elaborated schemas may offer sufficient leads to solve the near transfer tasks, which resemble the problems they observed during training, regardless of the type of pacing and structure. Conversely, these elaborated schemas may provide connections (e.g., with their prior knowledge) which enables learners to solve far transfer tasks. Possibly, on this level the guidelines for pacing and structure become relevant again. Here the second question is raised: Why is the pattern of differences between conditions not the same as in Experiment 1? The argument that the actual control that can be exerted over the instructional material should be in line with the expected level of control can only partially explain the differences found on far transfer. Possibly, for being able to perform far transfer tasks, learners should have control over the continuous animation rather than only its segments (i.e., full control) in order to process the given information more comprehensively. In the learner paced continuous condition learners can exert such full control, but in the learner paced segmented and computer paced continuous conditions this is not the case.

As was the case in experiment 1, the differences between expected level of control and actually available level of control are not reflected in the mental effort scores during instruction and the near and far transfer tests. The explanation given in the discussion of Experiment 1 might apply here as well.

General Discussion

The aim of this study was to investigate how learning from animated models could be optimized. For this purpose, guidelines for pacing and structure were used. We argued that in previous research the relation between pacing and structure was not investigated to its full extent. In the current study a comprehensive comparison was conducted with the factors pacing (either learner pacing or computer pacing) and structure (either segmented animated models or continuous animated models). Moreover, we included modality, that is, the use of spoken or written explanatory text in the study. According to the modality effect, complex pictorial information should best be accompanied by spoken explanatory text. In Experiment 1 using spoken explanations an interaction was found between pacing and structure on near transfer. Whereas learners with learner pacing performed better with continuous animated models, learners with computer pacing performed better with segmented animated models. Moreover, the post hoc analysis revealed that both the learner paced continuous condition and the computer paced segmented condition performed better on near transfer than the learner paced segmented condition. In Experiment 2 using written explanations an interaction between pacing and structure was found on far transfer. An additional analysis revealed that the learner paced continuous condition performed better than the learner paced segmented and the computer paced continuous condition. We suggested that for spoken explanations the similarity between the expected level of control over instructional material and the actually available level of control may be an important issue when near transfer tasks are involved. For far transfer also full control (rather than only control over segments) may be required in order to process information comprehensively. In addition, we argued that complex written explanations, contrary to transient complex spoken explanations, enabled learners to select and organize words in order to construct richer schemas that may provide more connections (e.g., with prior knowledge) to solve far transfer tasks.

The results of this study provide additional support for a further qualification of the modality effect. Recently, Tabbers, Martens, and van Merriënboer (2004) found that pacing was an important factor with regard to modality as written explanations were more effective than spoken explanations when learners had control over the pacing of the presentation. They argued that the absence of time pressure for learner pacing allowed learners to read the written text more strategically and to process the information more elaborative. Available time and the cognitive resources to process information seem all the more important with complex tasks, such as in problem solving, which requires learners to relate many information elements in order to construct an adequate schema. The construction of such adequate schemas requires learners to select and organize relevant words from the textual explanation (Clark & Paivio, 1991; Mayer & Moreno, 2003). The transient nature of spoken explanations, however, implies that learners have to keep information constantly active in working memory in order to select and organize relevant words. Keeping the words in working memory (e.g., repeat words silently in order to retain the information) requires cognitive resources that hence cannot be employed for relevant learning activities. Especially under time pressure or when explanatory text is complex this can pose a problem because learners may not be able to select all elements form the textual explanation. As a consequence spoken explanations yield less elaborated schemas, that is, schemas that contain a limited number of elements and hence less relations between those elements. These schemas are only applicable to problems similar to the ones solved during learning. Conversely, under appropriate conditions the more elaborate schemas stemming from written explanations may be applicable to problems that deviate from the ones solved during learning. Concluding, whereas written explanations with animated models may foster far transfer, spoken explanations may only foster near transfer. Consequently, more research is required in which the effect of modality is investigated with variations in the complexity of the textual explanations.

Our results also shed a new light on research regarding pacing. To start with, the results of Experiment 1 indicate that it is not only important to take into consideration whether learner pacing or computer pacing should be applied, but also to take into account what the relation is between the expected level of control and the actual control that can be exerted by the learners. This may also apply to learner control in general, of which pacing is only one specific type. Then, the discrepancy between expected and actual control may be one of the reasons why research on the effectiveness of learner control in multimedia instruction has resulted in such mixed findings (for reviews see Niemiec, Sikorski, & Walberg, 1996; Williams, 1996). Support for the importance of perceived control comes from research in organizational and industrial psychology, which suggests that perceived control over the work situation is strongly associated with high levels of job satisfaction, performance, and motivation (Ajzen, 2002; Spector, 1986; Troup & Dewe, 2004). Secondly, it is often argued that learner pacing is an effective method for learners because it allows them to adapt the pace of the presentation to their cognitive needs. However, in this study the combination of learner pacing and segmentation yields low performance on both near transfer (Experiment 1) and far transfer (Experiment 2). The difference between learner pacing and computer pacing when segmentation is involved, indicates that segmentation per se does not pose a problem. Contrary to the studies in which the combination learner pacing and segmentation yielded best performance (see Table 1), students in this study were advanced novices. CLT research has shown that design guidelines that are beneficial for novices may be ineffective or even detrimental when applied to more proficient learners or experts (Kalyuga, Ayres, Chandler, & Sweller, 2003). Possibly, the combination of learner pacing and segmentation might be effective for novices, but ineffective (or even detrimental) for more experienced learners. In other words, it is not inconceivable that the dissimilarity between the expected and actual control works out more negative for advanced novices than for genuine novices. This makes it all the more important that future research is conducted on the relation between learners' perception of control and the actual control they can exert and on how this affects their learning behavior.

There are also some limitations of the present study. A first caveat is that learner pacing was implemented slightly different in the segmented and continuous conditions. Although there was a commonality in the fact that learners in both conditions could pause and start the animated model, learners in the segmented learner paced condition could freely navigate by skipping back and forth in the animated model. On the other hand, learners in the continuous learner paced condition could only restart the animated model form the beginning and they could not go forward. The interaction for pacing and structure on both near and far transfer performance should be viewed from that perspective. Furthermore, it should be taken into account that we used a domain in which a procedural task was modeled. The results cannot automatically be generalized to cause-and-effect oriented domains, such as science and the working of devices, which involve knowledge about components and their interactions to explain the behavior of the whole system. A final remark concerns the segmentation applied. Although the segmentation was implemented with care (i.e., with support from statistical and didactical experts and based on the results of a pilot study), the length and number of segments used might not have optimally supported the cognitive processing of the participants. In this respect another kind of segmentation might lead to other results.

Beside the suggestions mentioned earlier, the findings and conclusions provide clear implications for future research. We found an indication that the effect of modality might be different for near and far transfer performance. However, these results were obtained from two different experiments. Therefore, research is needed in which pacing, structure, and modality guidelines are investigated in an integrated design, in particular for learners with different levels of expertise. Another avenue for future research arises from the personal observation that learners were often passively observing the animated models. It was difficult to see which cognitive activities they actually engaged in. Therefore research should be conducted to explore ways to enable or stimulate learners to engage in more active cognitive behavior. Interesting in this respect is to have learners explicitly reflect on the information presented in the animated models. Finally, we found an interesting relation between learner pacing and continuous animated models. Yet, we do not know much about the way learners used this combination. For example, did they mentally segment the continuous animated models? Why did they use the learner pacing facilities so little and is the mere existence of the possibility to pause the animated models enough to give the learner a sense of control? These are interesting aspects that could be further investigated by using, for example, verbal reporting techniques to uncover the cognitive processes learners are engaged in.

To conclude, the two reported studies indicate that animated models can be effective educational tools provided that the structure of the animated model is attuned to the type of pacing, that is, that the expected level of control corresponds to the actually available level of control. In particular, the use of learner paced continuous animated models seems a promising instructional method to enhance near and far transfer performance.

Chapter 4 - Observational Learning from Animated Models: Effects of Modality and Reflection on Transfer

Abstract

Animated models use animations and explanations to teach how a problem is solved and why particular problem-solving methods are chosen. Often spoken explanations are proposed to accompany animations in order to prevent overloading the visual channel (i.e., the modality effect). In this study we adopt the hypothesis that the inferior performance of written text compared to spoken text is due to the fact that written text receives less attention and, consequently, less effortful processing. In a 2 x 2 factorial experiment (N = 96) with the factors modality (written, spoken) and reflection prompts (yes, no) the hypothesis is tested that prompted reflection requires learners to explicitly attend to written explanations and carefully process them, thus yielding higher transfer performance, whereas for spoken explanations prompted reflection would have no effect on transfer performance. The results indeed showed the hypothesized interaction between modality and reflection prompts. They suggest that the modality effect can be compensated for by having learners explicitly attend to the information and effortfully process it. This has implications for learning situations in which spoken explanations are no option, such as education for the hearing-impaired.

Modern educational theories advocate the application of modeling in learning environments that focus on learning by performing authentic tasks (Collins, Brown, & Newman, 1989; van Merriënboer & Kirschner, 2007). The current focus on lifelong learning and flexibility in task performance increasingly emphasizes the modeling of cognitive skills, such as problem solving and reasoning in a variety of domains (Jonassen, 1999). This type of modeling, also referred to as cognitive modeling, concerns covert cognitive processes that have to be explicated in order to become observable for learners. Moreover, in the last two decades, computer-based animations with verbal explanations are increasingly used to explicate the covert processes in cognitive modeling, especially for abstract concepts and processes (Casey, 1996; Chee, 1995; Collins, 1991). In addition, developments in computer technology have facilitated the authoring and application of pedagogical agents, that is, computer-based characters that support learners with verbal feedback and guidance in order to engage them in more active learning (Clarebout, Elen, Johnson, & Shaw, 2002). We refer to the combined use of animations with explanatory text and pedagogical agents in modeling as 'animated models'. These animated models illustrate the solving of, for instance, scientific problems (e.g., solving a problem about gravity), mathematical problems (e.g., probability calculation problems), and search problems (e.g., finding information on the Internet). The pedagogical agent functions as a social model and guides the learner through the animation, for example, by moving around the screen and guiding the learner's attention to specific parts of the animation, by addressing the learner in a personalized style and/or by showing which errors typically occur and how they may be avoided by the learner. For example, in solving a problem in the domain of probability calculation, it is important to know whether it is a 'drawing with or without replacement'. For novices this concept may be rather abstract and difficult to understand. An animation can visualize the concept by showing what is happening, for instance as shown in Figure 1, in a situation with mobile phones.

Figure 1. Screen shot of the 'Checking mobiles' animated model which displays and explains why this is a 'drawing without replacement'.

Imagine a mobile factory where in an assembly line six mobiles -each with a distinct color- are packed in a box. A controller blindly selects two mobiles to check them for deficiencies. The learner has to calculate the probability that the controller draws a yellow mobile and a blue mobile from the box. The animated model may show a box with six mobiles. The first mobile drawn from the box can be put away from the box. As shown in Figure 1, the pedagogical agent may move to the drawn mobile and explain that a mobile that is drawn should not be put back because you do not want to draw an already checked mobile again. Then the group of remaining mobiles in the box becomes encircled. The pedagogical agent moves to the box with mobiles and explains that the second mobile will be selected from the remaining mobiles.

A potential danger of showing the performance of a complex task with animations and textual explanations is to overload the limited cognitive capacity of learners. A theory that tries to align the structure of information and the way it is presented with human cognitive architecture is cognitive load theory (CLT: Paas, Renkl, & Sweller, 2003, 2004; Sweller, 1988, 1999, 2004; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Sweller, 2005). CLT distinguishes between different categories of cognitive load. Firstly, intrinsic load is related to the complexity of the domain, and secondly, extrinsic load is determined by the manner in which the information is presented to learners. The load imposed by information and activities that hinder the learning process is called 'extraneous', whereas the load related to information and activities that foster the learning processes is called 'germane'. Intrinsic, extraneous, and germane load are considered additive in that, taken together, the total load cannot exceed the memory resources available if learning is to be maximized (see Paas, Tuovinen, Tabbers, & Van Gerven, 2003). An important objective of CLT is to decrease extraneous cognitive load and to enable learners to engage in learning activities required to perform effectively in tasks that impose germane cognitive load. However, a reduction in extraneous cognitive load does not guarantee that learners will automatically engage in learning activities that impose germane cognitive load. In this study we investigate how extraneous cognitive load can be reduced in animated models and how the released cognitive capacity can be allocated to relevant learning activities that impose germane cognitive load. A potential source of extraneous cognitive load in complex animated models may occur when two (or more) sources of information must be processed simultaneously in order to derive meaning from subject matter. Typically, animated models comprise pictorial information and textual explanations forcing learners to mentally search, match, and integrate both sources of information, which imposes a high extraneous cognitive load on working memory.

One way to overcome this so-called split-attention effect is the application of the modality principle: Provide explanations in spoken format rather than in written format. When verbal material is presented in spoken rather than written format, cognitive demands on the visual channel are reduced which enables the learner to process the visual material and construct an adequate pictorial representation. Hence, the combined use of the visual channel for pictorial learning material and the verbal channel for the explanation of this material increases effectively available working memory capacity and facilitates learning (Ginns, 2005; Mousavi, Low, & Sweller, 1995). According to the cognitive theory of multimedia learning (Mayer, 2001; Mayer & Moreno, 2003), understanding new information involves the construction of separate mental representations for the verbal and the pictorial information and referential connections between these representations. Although the modality effect has proven its effectiveness (for a review, see Ginns, 2005), the use of the verbal channel is not always feasible. For example, when deafness or an impairment of the sense of hearing is involved the provision of spoken explanations is useless. Also some training tasks require the interpretation of auditory information or signals which may then interfere with spoken explanations. This may be the case in present-day air traffic where pilots not only have to deal with numerous visual tasks (e.g., monitoring the flight instruments), but also have to engage in voice communication with the air traffic controller. This raises the question whether an instructional strategy can be developed that enables learners to compensate for the modality effect, that is, to make use of written explanations just as effectively as of spoken explanations.

An alternative perspective on the role of modality assumes that spoken explanations automatically receive more conscious attention than written explanations (Hasher & Zacks, 1979; Melara & O' Brien, 1987; Patching & Quinlan, 2002; Posner, Nissen, & Klein, 1976). More recently, Foos and Goolkasian (2005) further elaborated on this hypothesis and found that the modality effect disappeared when written words received effortful and attentional processing. In their experiments they enforced effortful and attentional processing by either presenting so-called degraded words (e.g., grey bars through the word) or by having participants mentally rehearse the words. These studies indicate that learners are inclined to more effortful processing when they are prompted to pay attention to written explanations. This may pertain all the more to the modality effect, investigated in experiments in which learners have to process pictorial information and textual information. An instructional strategy that may stimulate learners to pay attention to written explanations is to have them reflect on the information. Reflection implies that learners have to generate thoughts and considerations about the provided information, and this at least requires them to rehearse the information. In addition, reflection may not only impel learners to rehearse the text but also to engage in the generation of self-explanations, that is, to explain what they have understood from the instruction. This self-explanation effect has proven to be a successful approach to engage learners in active processing of learning material (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Renkl, 1997; Renkl & Atkinson, 2002). Self-explanations enable learners to integrate the new information with their prior knowledge and thus create more elaborated schemas that result in higher transfer of learning (Chi, de Leeuw, Chiu, & LaVancher, 1994).

For learning from animated models in the domain of probability calculation, we hypothesize that the provision of reflection prompts stimulates learners to engage in effortful processing of written explanations and enables them to construct a coherent mental representation. In contrast, reflection prompts will have no effect for spoken explanations and thus not further facilitate the construction of a coherent mental representation. To test this hypothesis, a factorial design was used with the factors modality (written, spoken) and reflection (reflection prompts, no reflection prompts). If the hypothesis is true, we expect learners in the conditions with written explanations to benefit from reflection prompts yielding higher transfer performance, whereas learners in the conditions with spoken explanations are not expected to profit from reflection prompts and thus will not enhance their transfer performance.

Method

Participants

Participants were 98 pupils of pre-university education in the Netherlands (50 females and 48 males). Their mean age was 15.8 years (SD = .73). The participants were paid 10 euro for their collaboration. The experiment used a factorial design with the factors modality (written, spoken) and reflection prompts (yes, no). The participants were randomly assigned to one of the four conditions. The data of two pupils in the condition with written text and no reflection prompts was excluded due to technical problems. This resulted in 25 participants in the condition with written text and reflection prompts; 22 participants in the condition with written text and no reflection prompts; 25 participants in the condition with spoken explanations and reflection prompts, and 24 participants in the condition with spoken text and no reflection prompts.

Materials

The computer-based learning environment was developed with Flash MX. The computer-based learning environment consisted of the following parts: A demographic questionnaire, a prior-knowledge test, an instructional component, and an assessment component. All parts were user timed, that is, the participants could decide how much time they spent on each part.

Demographic questionnaire. The experiment started with a demographic questionnaire in which participants were asked to give information about gender, age, the profile of their study, and the mathematics subjects they engaged in as well as the difficulty level of these mathematics subjects.

Prior-knowledge test. The prior-knowledge test that followed the demographic questionnaire consisted of 8 open questions and 4 multiple-choice questions of varying difficulty. An example of an open question is:

> ‘You are playing a game with some friends and it is your turn to throw a dice. If you throw sixes you win. What is the probability that you throw sixes?’

An example of a multiple choice question is:

‘You have a deck of cards from which you select 4 cards. You want to get an ace, king, queen and jack in this specific order. Does it matter whether you put back the selected cards before each new selection or not?

a. Yes, your chances increase when you put back the selected cards
b. Yes, your chances decrease when you put back the selected cards
c. No, your chances remain the same whether you put back the selected cards or not
d. This depends on the number of jokers in the deck of cards’

Instructional component. The instructional component consisted of an introduction to probability calculation and the experimental treatment. The introduction comprised a brief explanation of concepts in probability calculation, such as randomization, individual events, complex events, and how counting can be used in calculating the probability. After this introduction, which was identical for all four groups, participants received condition-specific information about the learning environment. In this part the participants in the conditions with reflection prompts were notified beforehand that they had to reflect on the animated models. With a continue button the participant could start the experimental treatment which consisted of eight animated models demonstrating and explaining how to solve a particular probability calculation problem. An example of such a problem is

> ‘In a factory mobile phones are produced. On a production line the mobiles receive a cover in one of six colors before they are packed in a box. Each box contains six mobiles in the colors red, black, blue, yellow, green, and pink. Before a box leaves the factory two mobiles are selected randomly and checked on deficiencies. What is the probability that you select the yellow and the blue mobile from one box?’

The animated models were grouped in four problem categories which resulted from two important characteristics in probability calculation: The order of drawing (relevant vs. irrelevant) and replacement of drawing (without replacement vs. with replacement). For each problem category two animated models were presented to enable learners to recognize structural similarities and dissimilarities between problems and thus learn not only how to solve problems but also when to apply which procedure. Table 1 shows the order in which the animated models were presented.

Table 1. Order in which the animated models are presented and the distribution across the problem categories

Order of presentation	Context of animated model	Problem category
1	Mountainbike trip with your friend[1)]	Order relevant / without replacement
2	Running contest	
3	Mountainbike trip with your friend[1)]	Order relevant / with replacement
4	PIN code	
5	Mountainbike trip with your friend[1)]	Order irrelevant / without replacement
6	Checking mobiles in a factory	
7	Mountainbike trip with your friend[1)]	Order irrelevant / with replacement
8	Finding figures in a cereal box	

Note: 1) Animated models 1, 3, 5, and 7 share the same context. The problems that have to be solved are different.

Table 2. Explanatory text for the mobile animated model. At any moment, only the text in one row was visible to the participants

	Text
1	In a factory mobiles are produced. On a production line the mobiles receive a cover in one of six colours before they are packed. Each box contains six mobiles in the colours red, black, blue, yellow, green, and pink. Before a box leaves the factory two mobiles are selected randomly and checked on deficiencies.
2	What is the probability that you select the yellow and the blue mobile from one box?
3	The order of the drawing is not important. It only matters that both the yellow and the blue mobile are selected. Whether the yellow mobile is drawn first, and thereafter the blue mobile. Or first the blue mobile and then the yellow one, does not matter.
4	This is a drawing without replacement. When the first mobile is drawn, it can not be replaced. Otherwise you could draw a mobile that was controlled already. Of course that is not supposed to happen.
5	The order is important in this case. Therefore you can work with individual events. The probability of the first individual event is 2/6. The first mobile can be blue or yellow. From the six possibilities, two are correct.
6	The probability of the second individual event is 1/5. Suppose that the first controlled mobile was blue. The second mobile then has to be yellow. However, only five mobiles are still in the box.
7	The two events are independent. Therefore the two probabilities have to be multiplied: 2/6 * 1/5. The probability of the complex event is 1/15 or 0.067

In all conditions participants were presented the same eight animated models. All animated models were continuous and learner paced, that is, participants could use a pause and play button and they could restart the animated model from the beginning. Each animated model depicted the problem-solving process and was completed with supportive spoken explanations (conditions with spoken modality) or written explanations (conditions with written modality) by a pedagogical agent that was implemented as a dolphin. Table 2 provides an example of the explanatory text that was used for the mobile animated model. The animated pedagogical agent moved across the screen to focus the learners' attention while one of two possible problem-solving processes were explained and demonstrated. The method of individual events was applied in four animated expert models and implies that, first, the probability of individual events is calculated separately and, subsequently, the complex event is calculated by multiplying the individual events. For example, in the mobile phone problem first the probability of selecting the yellow and the blue mobile was calculated (respectively 2/6 and 1/5) and these two probabilities were subsequently multiplied for calculating the probability of the complex event. The method of counting was applied in the other four animated expert models. This method implies that all possible combinations are balanced by the correct number of combinations. For example, suppose someone calculates the probability to guess a PIN code consisting of 4 figures. For each figure 10 different numbers (0 up to and including 9) can be chosen, whereas for 4 figures 10*10*10*10, that is 10,000, possible combinations can be chosen of which only one combination is correct. In the animated expert models the pedagogical agent explicated which considerations underlie the choice of one of the two methods.

In the spoken explanations-reflection prompts condition the participants could listen to a narrated animated model which was spoken by a male voice without accent. Immediately after the last animated model in each problem category, that is, after the 'running contest', 'PIN code', 'Checking mobiles in a factory', and 'Finding figures in a cereal box ' animated models, participants received a screen with the question 'Please, write down how the problem in the last animation was solved'. Their reflection had to be written in a textbox on the screen and was logged. With a continue button they could then proceed to the next animated model. The spoken explanations-no reflection prompts condition was identical to the spoken explanations-reflection prompts condition except that no reflection prompts and thus no textbox appeared after the last animated model in each problem category. The written explanations-reflection prompts condition was identical to the spoken explanations-reflection prompts condition with the exception that the explanations were written and appeared in a text balloon - originating from the animated pedagogical agent- very close to the place in the animated model it was referring to (see Figure 1 for a screen shot of the written explanations condition). Finally, the written explanations-no reflection prompts condition was identical to the written explanations-reflection prompts condition except that no reflection prompts and thus no textbox appeared after the last animated model in each problem category.

In all conditions, after each animated model, the participants were asked to score the mental effort they perceived when they studied the animated model on a one-item 9-point rating scale based on Paas (1992; see also Paas et al., 2003). This scale ranged from ‘very, very little effort’ to ‘very, very much effort’.

Assessment component. After the instructional component with the eight animated models an assessment component followed consisting of twelve transfer tasks. An example of such a transfer task is:

> ‘In a pop music magazine you see an ad under the heading FOR SALE in which a ticket for a spectacular concert by your favorite pop group is offered. Unfortunately the last 2 digits of the telephone number, where you can obtain information about the ticket, are not readable anymore. You really like to have the ticket and decide to choose the 2 digits randomly. What is the probability that you dial the correct digits on your first trial?’

Procedure

The experiment was conducted in one session and was run in the computer rooms of the participating schools. Each computer had a headset to listen to the verbal explanations. After welcoming the participants, the experimenter gave them a code to log in on the experimental environment. When the participants entered the environment, the purpose of the experiment was explained on the computer screen and an outline was given of the different parts of the experiment. First, participants had to fill out the demographic questionnaire on the computer. Then, the prior-knowledge test was conducted. The instruction phase started after the prior-knowledge test with the brief introduction to probability calculation. After reading the introduction participants could press a continue button to study the animated models. After each animated model, they were asked to score their perceived mental effort. By pressing a button they could proceed to the next animated model. After two animated models, participants in the conditions with reflection prompts received a screen in which they had to reflect on the last presented animated model. Following the instruction phase, the participants were presented the transfer test. Participants could use a calculator as well as scrap paper during the transfer test. All input to the calculator was logged and the scrap paper was collected after the experiment. After each transfer item they were asked to score their invested mental effort. Finally, the participants were debriefed and thanked for their participation.

Scoring

For each open question of the prior-knowledge test a list of correct answers was formulated. For each correct answer 1 point was assigned, otherwise 0 points. Computational errors were ignored and no partial credits were awarded. For each correct multiple-choice question participants received 1 point, otherwise they received 0 point. In total the maximum score on the prior-knowledge test could be 12 points. The mental effort scores after studying the animated models were summed across all eight animated models and divided by 8, resulting in an average score on mental effort ranging from 1 to 9. For each transfer task a list of correct answers was formulated. Computational errors were ignored and no partial credits were awarded. Each transfer task was assigned 1 point when it was correct and 0 points when it was incorrect. The maximum score for the transfer test was therefore 12 points. The mental effort scores after solving the transfer tasks were summed across the 12 transfer tasks and divided by 12, resulting in an average score on mental effort on transfer ranging from 1 to 9. Instruction time (in s) was defined as the time participants needed for the introduction (the basic theory of probability calculation) and the instruction component (the time spent on observing the animated models). For the conditions who received reflection prompts, the time spent on reflection was included in instruction time. The time (in s) needed to accomplish the transfer tasks was logged by the computer. The computer logged both the start time and the end time of the instruction.

Results

The dependent variables under investigation were instruction time (s), mental effort during instruction (score 1-9), performance on transfer (score 0-12), mental effort on transfer (score 1-9), and time on transfer tasks (s). For all statistical tests a significance level of .05 was applied. Effect sizes are expressed in terms of omega-squared (w^2). We began our analysis with testing the dependent measures that could be used as covariates for further analyses. Table 3 shows the mean scores and standard deviations of performance on the prior-knowledge test and the dependent variables for all conditions.

The mean score on the prior knowledge test was 6.00 (SD = 2.05), indicating that the participants had some knowledge (the maximum score was 12) regarding the subject matter. Research has shown that the level of prior knowledge interacts with the effectivity of instructional material, that is, design guidelines that are beneficial for novice learners can be ineffective or even detrimental when applied to experts (Kalyuga, 2005; Kalyuga, Ayres, Chandler, & Sweller, 2003).

Moreover, it is found that in the domain of probability calculation the level of prior knowledge has an effect on the quality of self-explanations (Atkinson, Renkl, & Merrill, 2003). Therefore the prior-knowledge score was included as a covariate (see also Atkinson, 2002). For instruction time, an ANOVA with the between-subjects factors modality and reflection showed a significant effect of reflection ($F(1, 92) = 51.01$, MSE = 100,769.26, $p = 0$, w^2 = 34%), indicating that learners in the reflection conditions needed more instruction time than learners in the no reflection conditions (M = 2,124 and SD = 382 vs. M = 1,659 and SD = 219). No main effect of modality ($F(1, 92) < 1$, *ns*) nor an interaction between modality and reflection was found $F(1, 92) < 1$, *ns*). Next, we tested for time on transfer tasks to determine whether it should be used as a covariate in further analyses. No differences were found on time on transfer tasks for modality, $F(1, 92) < 1$, *ns*), and reflection, $F(1, 92) = 2.76$, MSE = 213,218.43, *ns*). No interaction for modality and reflection was found on time on transfer tasks ($F(1, 92) = 3.04$, *ns*).

Table 3. Mean scores and standard deviations on performance on the prior knowledge test and dependent variables for all conditions

	Written explanations						Spoken explanations					
	Reflection prompts			No reflection prompts			Reflection prompts			No reflection prompts		
	M	SD	AM	M	SD	AM	M	SD	AM	M	SD	AM
Prior knowledge test (0 -12)	5.76	2.20		7.00	1.85		5.76	2.06		5.70	1.57	
Instruction												
Instruction time (s)	2,103	380		1,681	220		2,145	389		1,639	220	
Mental effort during instruction (1-9)	2.83	1.26	2.68	2.76	1.08	2.90	2.29	.93	2.11	2.51	1.09	2.70
Transfer Test												
Performance on transfer (0-12)	5.12	2.06	5.26*	4.54	1.50	4.00*	4.16	2.39	4.29	4.79	2.26	4.99
Mental effort on transfer (1-9)	4.15	1.77	3.97	4.08	1.80	4.47	4.63	1.45	4.42	4.71	1.80	4.77
Time on transfer tasks (s)	1,446	445		1,438	454		1,257	466		1,579	479	

Note: AM means adjusted means. Scores with * differ statistically (i.e., written explanations with reflection prompts performs better than written explanations with no reflection prompts).

For each measure the homogeneity of regression was tested and all results were found to be nonsignificant, $F < 2.3$. Therefore, scores were analyzed with ANCOVAs with the between-subjects factors modality (spoken explanations vs. written explanations) and reflection (reflection prompts vs. no reflection prompts), and the covariates prior knowledge and instruction time. For performance on transfer no difference could be observed for either modality ($F(1, 92) < 1$, *ns*) or reflection ($F(1, 92) < 1$, *ns*). However, the interaction between modality and reflection on performance on transfer, which is depicted in Figure 3, was significant, $F(1, 92) = 6.81$, $MSE = 3{,}2307$, $p = .011$, $w^2 = 4\%$.

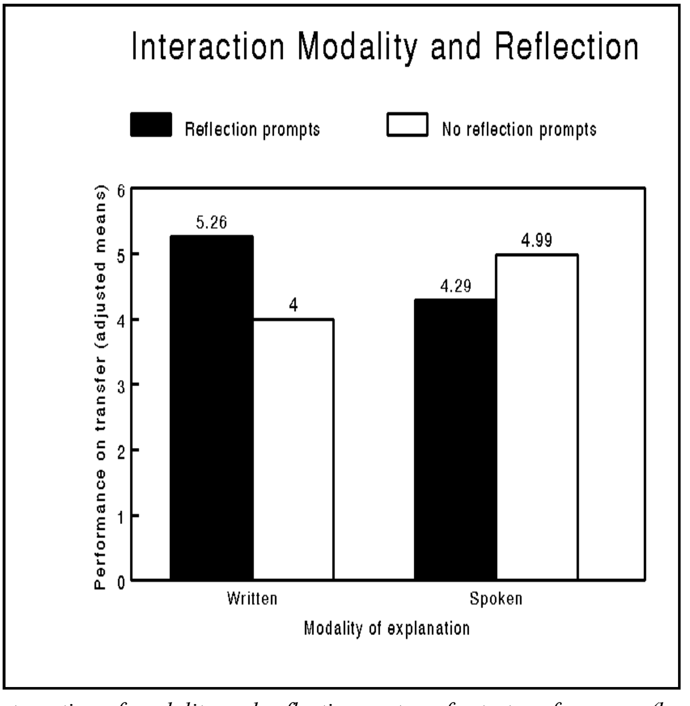

Figure 3. The interaction of modality and reflection on transfer test performance (based on adjusted means).

The interaction indicates that written explanations yielded better transfer performance with reflection prompts than without reflection prompts ($M = 5.12$, $SD = 2.06$ with reflection vs. $M = 4.54$, $SD = 1.50$ with no reflection), whereas for spoken explanations no difference was found between reflection prompts and no reflection prompts ($M = 4.79$, $SD = 2.26$ with no reflection vs. $M = 4.16$, $SD = 2.39$ with reflection). Post-hoc multiple comparisons based on the adjusted means were conducted using Bonferroni's procedure. This analysis showed that learners in the condition with written explanations and reflection prompts performed better on transfer than the learners with written explanations without reflection prompts. The other comparisons revealed no differences.

For mental effort during instruction no difference was found for either modality ($F(1, 92) = 2.96$, $MSE = 1{,}189$, *ns*) or reflection ($F(1, 92) = 1.95$, *ns*), nor an interaction between modality and reflection was observed ($F(1, 92) < 1$, *ns*). Finally, no differences were observed on mental effort on transfer for either modality ($F(1, 92) = 1.20$, $MSE = 2{,}706$, *ns*) or reflection ($F(1, 92) < 1$, *ns*), nor an interaction between modality and reflection was found ($F(1, 92) < 1$, *ns*).

Discussion

The aim of this study was to investigate whether the modality effect could be compensated for by having learners attend and effortfully process the written explanations. In line with our hypothesis, learners who received written explanations with reflection prompts yielded higher performance on transfer tasks than those who received written explanations without reflection prompts. For spoken explanations, no difference on transfer performance between reflection prompts and no reflection prompts was observed. No effects were found on mental effort during instruction and mental effort on transfer. The mental effort measure used did not differentiate between mental effort due to perceived difficulty of the subject matter, presentation of the instructional material, or being engaged in relevant learning activities. It is possible that the effect on the perceived mental effort of the varying design guidelines, that is, modality and reflection prompts, have neutralized each other. For example, during the instruction the reflection prompts may have yielded an increase in germane load for the written explanation condition, but at the same time have decreased the intrinsic cognitive load due to a better understanding of the subject matter. The absence of reflection prompts in the written explanation with no reflection prompts condition, on the other hand, may neither have yielded an increase in germane cognitive load nor a decrease of intrinsic cognitive load.

From a theoretical point of view these results contribute to a better understanding of the modality effect. The modality effect in multimedia learning assumes that working memory is used more effectively when the verbal channel is used for spoken explanations and the visual channel for the pictorial or visual information. According to this view, accompanying complex visual materials with written explanations may result in too much load on the visual channel and thus to inferior processing of the instructional materials (Ginns, 2005; Mousavi, Low, & Sweller, 1995). An alternative explanation, with a focus on attentional processing, alleges that the modality effect can be ascribed -at least partly- to the fact that written text receives less attention and effortful processing (Foos & Goolkasian, 2005). When learners are stimulated to attend to this information by mentally rehearsing or repeating the textual information, spoken text is no longer superior to written text. The results of the present study suggest that the role of attention in modality also pertains to multimedia learning. Moreover, these results further corroborate the findings of other studies in which the interpretation of the modality effect in multimedia learning has been questioned. For example, Tabbers, Martens, and van Merriënboer (2002, 2004) found that written explanations were more effective than spoken explanations when learners had control over the pace of presentation. This was ascribed to the lack of time pressure in learned-controlled conditions, which enabled learners to take full advantage of the characteristics of written media and read the written explanations in such a way that they could select relevant parts of the text and skip irrelevant parts. Apparently, there are conditions (self-pacing, prompting attention) under which the modality effect does not hold true anymore.

Interestingly, it was found that learners with spoken explanations and reflection prompts performed slightly worse on transfer tasks than those who did not receive reflection prompts ($M = 4.29$ for reflection prompts vs. $M = 4.99$ for no reflection prompts). This suggests that the reflection prompts may have interfered with the processing of the spoken explanations. Some evidence for this hypothesis comes from studies by De Beni and colleagues (De Beni, Moè, & Cornoldi, 1997; De Beni & Moè, 2003; Moè & De Beni, 2005). In their studies they combined modality (spoken and written texts) with instruction strategy (imagery vs. mental rehearsal) and found that on a free recall test written texts yielded better performance when a mental rehearsal strategy was used, whereas spoken texts yielded better performance with an imagery strategy. These results were explained with the 'selective interference hypothesis' which states that performance will be disrupted when two tasks or processes are executed in the same channel (i.e., the verbal or visual channel), but not when executed in different channels (see also Penney, 1989). In the case of written texts the mental rehearsal process will take place in the verbal channel which still has sufficient resources available. An imagery strategy would impose load on the visual channel and thus interfere with the processing of the written texts. When spoken texts are involved the pattern is reversed: Mental rehearsal may interfere with the processing of the spoken text in the verbal channel, whereas imagery facilitates learning since it takes place in the visual channel. Cognitive load theory research on the imagination effect also provides some support that such interference may occur. The imagination effect is derived from studies involving motor skills which have shown that imagining motor skills before actually performing them leads to better results compared with not imagining motor skills before performing them (Cooper, Tindall-Ford, Chandler, & Sweller, 2001). In the cognitive domain, imagination contains that learners have to imagine how a procedure is performed. Tindall-Ford and Sweller (2006) have shown that imagination was more effective when visual material was explained by spoken texts rather than written texts. In their study, however, the explanatory text was physically separated from the part of the diagram it was referring to. This indicates that visual search may have occupied the visual channel so much that little capacity remained for imagination. Some support for this view follows from Leahy and Sweller (2004) who found that imagination was more effective in interpreting contour maps and graphs about weather when explanatory labels were integrated (i.e., less visual search) rather than presented on a separate page (i.e., much visual search). If the selective interference theory holds true, it is possible that the modality effect is contingent on the kind of active processing that learners engage in. For this reason more research is required on the interaction between the modality of presentation and design guidelines that foster active processing.

On the practical side the results of this study may have implications for instructional designers, in particular when spoken explanations are no option such as in the education of the hearing-impaired. Written explanations combined with visual material can be an effective learning arrangement provided that learners are stimulated to process these written explanations, for example by prompting them to reflect. Conversely, reflection takes more instruction time, but it does not pay back in better performance when it is combined with spoken explanations. This is all the more important since the creation of spoken explanations for animations is more time-consuming and expensive than the creation of written explanations

The findings and conclusions also provide directions for future research. To start with, it should be noted that learners in the condition with reflection prompts had to reflect in a written format (i.e., they typed their considerations in a text box) regardless of the modality of the explanations. From this point of view, learners in the condition with written explanations may have had an advantage because the way they could express their reflection was more in line with the modality of received explanations. For this reason a replication study is required in which not only the modality of the explanations is varied but also the format in which the learners reflect (i.e., spoken or written). Secondly, the reflection prompts used in our study asked learners to reflect on how the problems were solved, that is, it prompted learners to focus on the method that was used to solve the problem. However, reflection can also be implemented by asking learners to explain a correct answer or solution given in a multimedia learning environment (Moreno & Mayer, 2005). An interesting avenue for future research therefore might be to compare the effects of reflection and modality when learners are prompted to think about how a problem was solved, why in their opinion the solution was correct, or a combination of both. Thirdly, modeling is about observing someone performing a complex skill with the intention to perform the problem solving skill yourself in a later stage. Reflection can be regarded as a link between observing and performing: Learners do not yet perform the problem solving skill, but they actively think about the solution without solving the problem. A next step might be to alternate between observing the problem-solving process and independently solving a novel problem. Modeling research in the domain of motor skill acquisition has shown evidence that learners benefit from alternating between observing and practicing (Shea, Wright, Wulf, & Whitacre, 2000; Weeks & Anderson, 2000). Consequently, comparing an arrangement in which learners only observe performance in the domain of problem solving with a situation in which observation and practicing are alternated could ground a better understanding of the relation between observing and practicing.

Finally, the results of this study have some clear limitations. To start with, the instructional material was only used with one particular type of learners (i.e., pupils of pre-university education) who also had some relevant prior knowledge. Secondly, a specific domain was used, that is, probability calculation, which is procedural in nature rather than describing a causal chain of events (e.g., science). Thirdly, the learner reflections were limited in both their modality (i.e., learners could only reflect in written format) and their quantity (i.e., learners were prompted to reflect only four times, after the last animated model in each problem category). In addition, the results are limited because the experiment included two different aspects regarding reflection. Beside the fact that the participants had to reflect, they were also informed beforehand that they had to reflect. It is not clear whether the results can be ascribed to the reflection process, the notice beforehand, or a combination of both. Our study showed that reflection prompts might compensate for the modality effect, but more research is needed to further specify the conditions under which such compensation occurs.

Chapter 5 - Observational Learning from Animated Models: Effects of Perceived Control and Study-Practice Alternation on Transfer Performance

Abstract

Animated models explicate how a problem is solved and why particular methods are chosen to solve it. They are expected to be effective learning tools for novices, especially when abstract cognitive processes and concepts are involved. Cognitive load theory was used to investigate how learners might be stimulated to engage in genuine learning activities. Perceived control was identified as an important contributor to motivation. It was hypothesized that high perceived control yields higher transfer performance than low perceived control. Moreover, we hypothesized that learners who first studied an animated model and then solved the same problem would perform better on transfer tasks than learners who studied the same animated model twice or who first solved the problem and then studied the animated model. In a 2 x 3 factorial experiment (N = 90) with the factors perceived control (low vs. high) and instructional method (study-practice, practice-study, study-study) only the first hypothesis was confirmed. Implications for the design of animated models are discussed.

Observing a model who performs the desired actions and behavior has been a successful and well investigated instructional technique for the last 30 years in the field of motor learning (McCullagh, Weiss, & Ross, 1989; Wetzel, Radtke, & Stern, 1994; Wulf & Shea, 2002). The application of cognitive modeling in learning environments that focus on problem solving and reasoning in a variety of domains is increasingly advocated by modern educational theories (Collins, Brown, & Newman, 1989; Jonassen, 1999; van Merriënboer & Kirschner, 2007). Cognitive modeling concerns covert cognitive processes that have to be explicated in order to become observable for a learner. At the same time, rapid developments in computer and software technologies in the last decades have enabled the use of dynamic visualizations, such as animations and video, to illustrate abstract cognitive processes and concepts (Casey, 1996; Chee, 1995). In addition, developments in computer technology have facilitated the authoring and application of 'pedagogical agents', that is, computer-based characters that support learners with verbal feedback and guidance in order to engage them in more active learning (Clarebout, Elen, Johnson, & Shaw, 2002).

We refer to the combined use of animations with textual explanations and pedagogical agents in cognitive modeling as animated models. These animated models illustrate the solving of, for instance, scientific problems (e.g., solving a problem about gravity), mathematical problems (e.g., probability calculation problems), and search problems (e.g., finding information on the Internet). The pedagogical agent functions as a social model and guides the learner through the animation, for example, by moving around the screen and guiding the learner's attention to specific parts of the animation, by addressing the learner in a personalized style, and/or by showing which errors typically occur and how they may be avoided. For example, in solving a problem in the domain of probability calculation, it is important to know whether it is a 'drawing with or without replacement'. For novices this concept may be rather abstract and difficult to understand. An animation can visualize the concept by showing what is happening, for instance, in a situation with mobile phones.

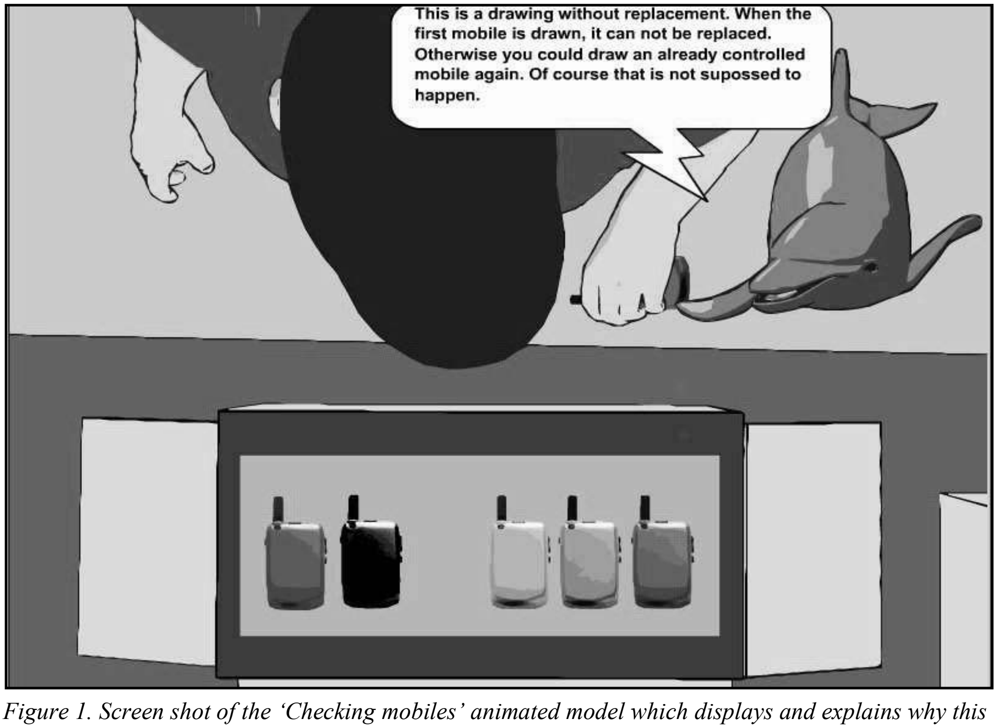

Figure 1. Screen shot of the 'Checking mobiles' animated model which displays and explains why this is a 'drawing without replacement'.

Imagine a mobile factory where on an assembly line six mobiles -each with a distinct color- are packed in a box. A controller blindly selects two mobiles to check them for deficiencies. The learner has to calculate the probability that the controller draws a yellow and a blue mobile from the box. The animated model may show a box with six mobiles. The first mobile that is drawn from the box can be visibly moved aside from the box. As is shown in Figure 1, the pedagogical agent (i.e., the dolphin) may move to the drawn mobile and explain that a mobile that is drawn should not be put back because you do not want to draw an already checked mobile again. Then the group of remaining mobiles in the box becomes encircled. The pedagogical agent moves to the box with mobiles and explains that the second mobile will be selected from the remaining mobiles, and so forth.

A potential danger of showing the performance of a complex task with animations and textual explanations is to overload the limited cognitive capacity of learners. A theory that tries to align the structure of information and the way it is presented with human cognitive architecture is cognitive load theory (Paas, Renkl, & Sweller, 2003, 2004; Sweller, 1988, 1999, 2004; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer & Sweller, 2005). Cognitive load theory identifies three types of cognitive load. The first type, intrinsic cognitive load, is caused by the complexity of the subject matter and cannot be altered without compromising sophisticated understanding (Paas et al., 2004). Also the way that information is presented can impose a cognitive load. The second type, extraneous cognitive load, is imposed on working memory because of poorly designed instructional material. The third type, germane cognitive load, is imposed when information is presented in such a way that learning is enhanced, for example, because the learner engages in cognitive activities like elaborating, abstracting, and inferring. In turn, these activities result in the construction and automation of cognitive schemas, that is, structures representing generalized descriptions of two or more problems and their associated solutions (Cooper & Sweller, 1987). An important objective of cognitive load theory is to decrease extraneous cognitive load and to enable learners to engage in learning activities that impose germane cognitive load.

The central question in this study is how learners can be stimulated to invest effort in learning, in particular, to increase germane cognitive load through more effective processing of newly presented information. We will investigate this question from two perspectives. The first departs from the stance that cognitive load theorists increasingly emphasize the motivational aspects of learning (Gerjets & Scheiter, 2003; Paas et al., 2003; Paas, Tuovinen, van Merriënboer, & Darabi, 2005; van Merriënboer & Sweller, 2005). Motivation is assumed to be a major contributor to the willingness of learners to engage in genuine learning activities (van Merriënboer & Ayres, 2005). However, for learning to commence, instructional strategies should be used that effectively guide the learner's investment of mental effort and take account of the learner's limited cognitive capacity. This is the focus of the second perspective, which builds on the assumption that learners have to be stimulated to engage in active processing of learning materials in order to fully understand the presented information (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Mayer, 2001; Wittrock, 1974).

With regard to the first perspective, a potential instructional technique to increase the motivation of learners is giving them control over the learning process (Kinzie, 1990). However, reviews focusing on several dimensions of learner control are not conclusive with respect to the benefits of learner control (Kay, 2001; Lin & Hsieh, 2001; Niemiec, Sikorski, & Walberg, 1996; Williams, 1996). In a review study, Skinner (1996) classified the multiplicity of constructs of control. One of the most fundamental distinctions is that between the perceived control of learners and the actual control that they can exert. The question can be raised what will occur when perceived control and actual control are not in line. Cognitive dissonance theory (Festinger, 1957) argues that individuals seek consistency among their cognitions (i.e., beliefs, opinions, observations) and that a dissonance will occur in the case of an inconsistency between these cognitions. For example, participants in a study on the effects of control and effort on the cardiovascular and the endocrine systems (Peters et al., 1998) were notified beforehand that they could exert control over the intensity of noise during task performance. However, only the participants in the control conditions were allowed to actually exert control over the noise. Participants who could not control the intensity of the noise, although they were told they could, experienced higher levels of stress, indicated by higher activation of the sympathetic nervous system (e.g., higher blood pressure) which is associated with stressing factors. In addition, some evidence exists that this dissonance may undermine task performance (Elliot &

Devine, 1994; Pallak & Pittman, 1972). The expected level of control can be regarded as a cognition in the sense that it is a belief of a learner, whereas the actual level of control is considered a cognition since it is an observation made by a learner. Under this assumption, a dissonance and thus a negative effect on learning may occur when learners expect more control than they can actually employ. Some supportive evidence follows from earlier research in which we found that learners who had control over animated models divided in predefined segments performed worse on transfer performance than learners who could control a continuous animated model and thus define their own segments (Wouters, Paas, & van Merriënboer, 2007). The learners in the learner paced segmented condition might have expected a high level of control over the instructional material, but found the material to be largely controlled by the fixed segmentation. In the learner paced continuous condition the learners probably expected a high level of control and they were indeed enabled to exert such control (i.e., they could segment the animated model themselves).

With regard to the second perspective, research has shown that novices in a domain benefit from instructional methods that have them carefully study worked out solutions of problems (see for a review, van Merriënboer & Sweller, 2005). But studying worked out solutions has also some disadvantages. To start with, the passivity inherent to only studying worked out solutions may undermine the motivation of learners. Secondly, it may result in learning only stereotyped problem solutions that may not be applicable to problems that differ from the ones learned during training (Sweller et al., 1998). Finally, once a learner understands the rationale behind the worked out solutions, the presentation of additional worked out solutions merely presents redundant information, and the cognitive load associated with studying the solutions will turn from germane (i.e., constructing a schema of solution steps) to extraneous (i.e., finding out that the solution steps are already known; Renkl & Atkinson, 2003).

In this respect the generation of self-explanations, in which learners try to explain the rationale of a problem solution to themselves, has proven to be an effective instructional method (Chi et al., 1989; Renkl, 1997; Renkl & Atkinson, 2002; Roy & Chi, 2005). Also the provision of example-practice pairs, that is, learners first study a worked out solution and subsequently try to solve a similar problem themselves , has proven to be an effective way to introduce problem solving elements (Reisslein, Atkinson, Seeling, & Reisslein, 2006; Sweller & Cooper, 1985; Trafton & Reiser, 1993). For novices, however, solving new problems after studying only one example may yet impose such a high cognitive load that negative effects on learning occur. Therefore, the ‘completion strategy’ has been proposed (Sweller, van Merrienboer, & Paas, 1998), in which the problem is only partly solved and the learner has to complete the partial solution by adding missing solution steps.

The conjunction of first studying a worked-out solution and subsequently solving the same problem provides an alternative for the completion strategy, in which self-explanations and worked out solutions are combined. During the study stage of the study-practice sequence learners process specific information they would not be able to process when practicing the problem solving skill directly from the beginning, because of the high demand of problem solving on cognitive resources. After the study stage learners have constructed a preliminary schema that can be further refined in the practice stage, through the information originating from actually performing the problem solving skill (Shea, Wright, Wulf, & Whitacre, 2000; Weeks & Anderson, 2000; Wulf & Shea, 2002). The alternation between first studying and then practicing enriches the problem solving schema, and also helps learners to integrate newly learned information with their prior knowledge, yielding a more integrated knowledge base with increased accessibility, better recall, and higher transfer of learning.

In learning from animated models in the domain of probability calculation, we hypothesize that learning and thus task performance will deteriorate when learners expect more control than they can actually employ in the learning environment (i.e., a negative dissonance occurs). Moreover, we hypothesize that the alternation of studying an animated model of a problem solution and then solving the same problem will result in more elaborated schemas than arrangements in which learners only study animated models or first solve the problem and only then study the animated model. In a factorial design with the factors level of perceived control (high, low) and instructional method (study-practice, practice-study, study-study) we predict that learners in the high perceived control conditions reach higher transfer performance than learners in the low perceived control conditions.

Furthermore, we predict that learners in the study-practice conditions outperform learners in the practice-study and study-study conditions on transfer tasks.

Method

Participants

Participants were 90 pupils of pre-university education in the Netherlands (51 females and 39 males). Their mean age was 15.7 years (SD = .72). The participants were paid 10 euro for their collaboration. The participants were randomly assigned to one of the six conditions. This resulted in 15 participants in each of the conditions.

Materials

The computer-based learning environment was developed with Flash MX and consisted of the following parts: A demographic questionnaire, a prior knowledge test, an instructional component, a mental effort rating scale, and an assessment component. All parts were user timed, that is, the participants could decide how much time they spent on each part.

Demographic questionnaire. The experiment started with a demographic questionnaire in which information was asked about gender, age, the study profile, the mathematics subjects in the program, and the difficulty level of these mathematics subjects.

Prior-knowledge test. The prior knowledge test that followed the demographic questionnaire consisted of 8 open questions and 4 multiple choice questions of varying difficulty. An example of an open question is:

> ‘You are playing a game with some friends and it is your turn to throw a dice. If you throw sixes you win. What is the probability that you throw sixes?’

An example of a multiple choice question is:

> ‘You have a deck of cards from which you select 4 cards. You want to get an ace, king, queen, and jack in this specific order. Does it matter whether you put back the selected cards before each new selection or not?
>
> a. Yes, your chances increase when you put back the selected cards
> b. Yes, your chances decrease when you put back the selected cards

c. No, your chances remain the same whether you put back the selected cards or not
d. This depends on the number of jokers in the deck of cards'

Instructional component. The instructional component consisted of an introduction to probability calculation and the experimental treatment. The introduction comprised a brief explanation of the main concepts in probability calculation, such as randomization, individual events, complex events, and how counting can be used in calculating the probability. After this introduction, which was identical for all six groups, participants received condition-specific information about the learning environment. With a continue button participants could start the experimental treatment in which eight problems in probability calculation had to be solved. The probability calculation problems were grouped in four problem categories which resulted from two important characteristics in probability calculation: (1) The order of drawing (relevant vs. irrelevant) and (2) replacement of drawing (without replacement vs. with replacement). For each problem category two problems were presented to enable learners to recognize structural similarities and dissimilarities between problems and thus learn not only how to solve problems but also when to apply which procedure. An example of such a problem is:

> 'During your vacation you are invited to attend the running contest of the local Scouting club. Seven scouts participate in the running contest. What is the chance that you correctly guess the winner of the gold, silver, and bronze medal in this contest of seven runners?'

In order to cause expectations about learner control the condition-specific information in all conditions contained the following information:

> 'You will see a screen with 8 buttons. Each button refers to a problem in probability calculation. TAKE CARE! Although some problems look similar, they are really different. You have to select each button (and thus each problem), but you are free to select the order. Buttons that you have selected will be disabled. In the upper right corner of the screen with the buttons is a list in which the problems that you have selected are colored in red.'

As shown in Figure 2 the buttons in the conditions with low perceived control had meaningless names so that in fact learners did not know what they selected. The learning environment in the low perceived control conditions was adjusted in such a way that the problems were always presented in the same order as listed in the upper right corner. So, whether a learner for the first time pressed the button with the caption ‘Problem 7’ or the button with the caption ‘Problem 4’, the learning environment would start with the ‘Mountain bike ride 1’ problem.

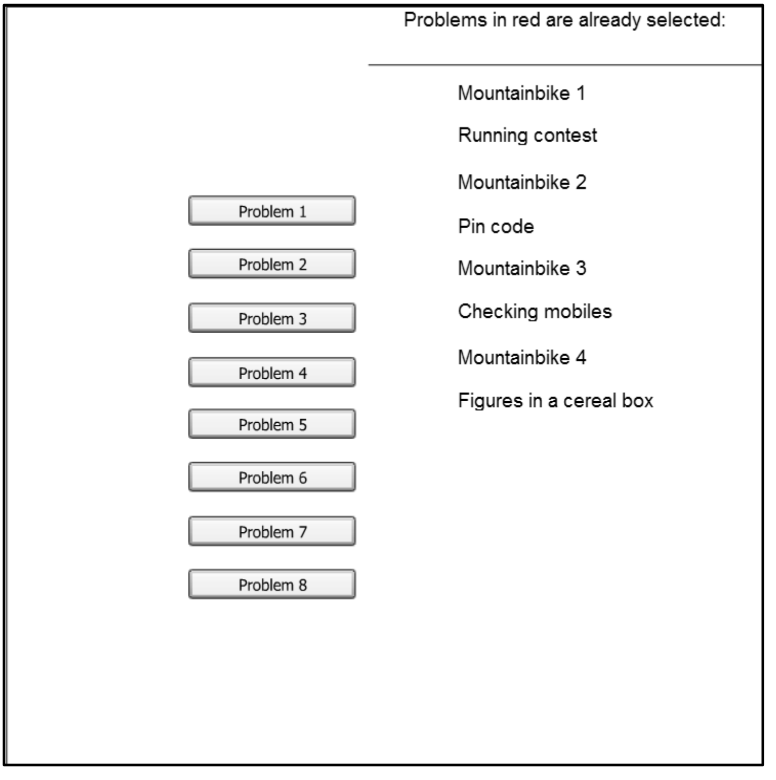

Figure 2. The screen with buttons from which learners could select problems in the low perceived control conditions.

Regardless which button the learner pressed the second time, the ‘Footrace’ problem would be the second presented problem, and so forth. Although learners in this condition expected control over the selection of problems, they gradually became aware that they did not have any control at all. As shown in Figure 3, the buttons in the conditions with a high level of perceived control had meaningful names. Moreover, the learning environment was adjusted in such a way that it responded to the selection of the learner. So, when a learner would select the 'Pin code' problem, this problem was presented. Learners in this condition expected control over the problem selection and could actually employ this control during the experiment.

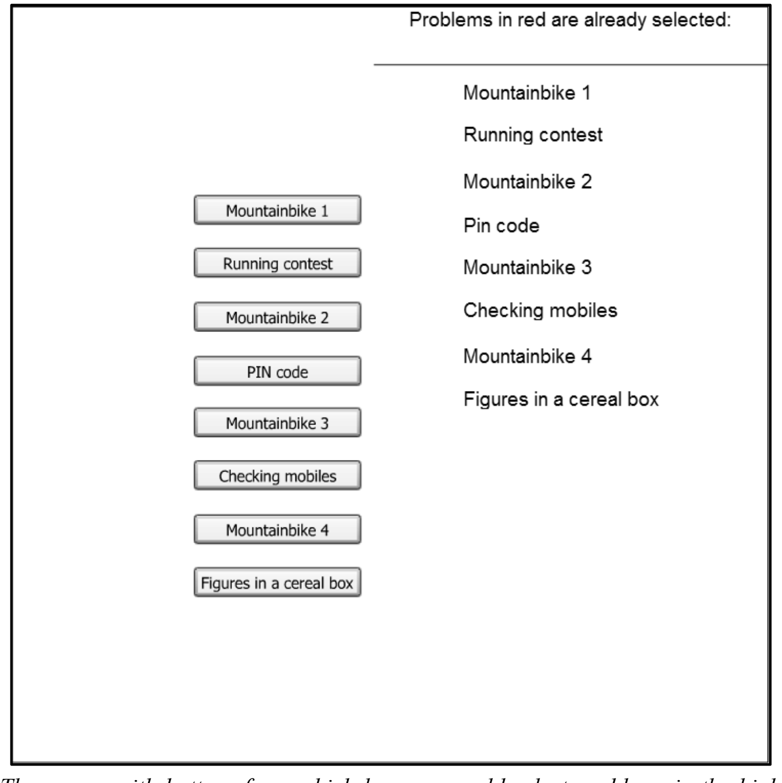

Figure 3. The screen with buttons from which learners could select problems in the high perceived control conditions.

The animated models in all conditions were continuous and learner paced, that is, learners could use a pause and play button. Each animated model lasted 120 seconds.

The problem-solving process in each animated model was completed with supportive written explanations by a pedagogical agent that was implemented as a dolphin. The animated pedagogical agent moved across the screen to focus the learners' attention while explaining and demonstrating one of two possible problem-solving processes: the method of individual events and the method of counting. The method of individual events was applied in four animated models and implies that, first, the probability of individual events is calculated separately and, subsequently, the complex event is calculated by multiplying the individual events. For example, in the 'checking mobiles' problem first the probability of selecting the yellow and the blue mobile was calculated (respectively 2/6 and 1/5) and these two probabilities were subsequently multiplied for calculating the probability of the complex event. The method of counting was applied in the other four animated models. This method implies that all possible combinations are balanced by the correct number of combinations. For example, suppose someone calculates the probability to guess a PIN code consisting of 4 figures. For each figure 10 different numbers (0 up to and including 9) can be chosen, whereas for 4 figures 10*10*10*10, that is 10.000, possible combinations can be chosen of which only one combination is correct. In the animated models the pedagogical agent explicated which considerations underlie the choice of one of the two methods.

The learning environment was configured in such a way that it could run in six modes reflecting the six conditions. In the two study-study conditions the participants observed an animated model in which a problem was solved two times in succession. In the two study-practice conditions learners observed an animated model in which a problem was solved once, where after the description of the same problem appeared on the screen with a text box below it in which they could solve the problem. Learners were forced to spend a minimum of 120 seconds solving the problem. When they tried to continue before the 120 seconds had passed, a message appeared which suggested to look again at the solution they had given. In the two practice-study conditions learners received a description of the problem on the screen with a text box in which they could solve the problem. The same time constraints and message were applied as in the study-practice conditions. After pressing a continue button an animated model was started, showing the solution of the problem they had just solved.

The three high perceived control conditions (high perceived control/study-study, high perceived control/study-practice, high perceived control/practice-study) were identical to the three low perceived control conditions (in order, low perceived control/study-study, low perceived control/study-practice, low perceived control/practice-study), with the exception that learners could determine the order of the problems they engaged in. In all conditions, after each problem, the participants were asked to score the mental effort they perceived when they engaged in the instructional activity on a one-item 9-point rating scale based on Paas (1992; see also Paas et al., 2003). This scale ranged from 'very, very little effort' to 'very, very much effort'.

Assessment component. After the instructional component with the eight problems an assessment component followed consisting of twelve transfer tasks. An example of a transfer task is:

> 'In a pop music magazine you see an ad in the rubric FOR SALE in which a ticket for a spectacular concert of your favorite pop group is offered. Unfortunately the last two digits of the telephone number, where you can obtain information about the ticket, are not readable anymore. You really like to have the ticket and decide to choose the two digits randomly. What is the probability that you dial the correct digits on your first trial?'

Procedure

The experiment was conducted in one session and was run in the computer rooms of the participating schools. After welcoming the participants, the experimenter gave them a code to log in on the experimental environment. When the participants entered the environment, the purpose of the experiment was explained on the computer screen and an outline was given of the different parts of the experiment. First, participants had to fill out the demographic questionnaire. Then, the prior knowledge test was conducted. The instruction phase started after the prior knowledge test with the brief introduction to probability calculation. After reading the introduction participants could press a continue button to engage in the experimental treatment. After each problem, participants were asked to score their perceived mental effort. By pressing a button they proceeded to the selection screen in which they could select the next problem. Following the instruction phase the transfer test was administered. Participants could use a calculator as well as scrap paper during the transfer test. All input to the calculator was logged and the scrap paper was collected after the experiment. After each transfer task they were asked to score their invested mental effort. Finally, the participants were debriefed and thanked for their participation.

Scoring

For each open question of the prior knowledge test a list of correct answers was formulated. For each correct answer 1 point was assigned, otherwise 0 points. Computational errors were ignored and no partial credits were awarded. For each correct multiple-choice question participants received 1 point, otherwise they received 0 points. In total the maximum score on the prior knowledge test was 12 points. The mental effort scores gathered after each problem were summed across all eight problems and divided by 8, resulting in an average score on mental effort ranging from 1 to 9. For each transfer task a list of correct answers was formulated. Computational errors were ignored and no partial credits were awarded. Each transfer task was assigned 1 point when it was correct and 0 points when it was incorrect. The maximum score for the transfer tasks was therefore 12 points. The mental effort scores gathered after each transfer task were summed across the 12 transfer tasks and divided by 12, resulting in an average mental effort score on transfer ranging from 1 to 9. Instruction time (in s) was defined as the time participants needed for the introduction (the basic theory of probability calculation) plus the instructional component (i.e., the time spent on the eight problems). The time (in s) needed to accomplish the transfer tasks was logged by the computer. The computer logged both the start time and the end time of the instruction.

Results

The dependent variables under investigation were instruction time (s), mental effort during instruction (score 1-9), performance on transfer (score 0-12), mental effort on transfer (score 1-9), and time on transfer tasks (s). For all statistical tests a significance level of .05 was applied. Due to technical failure the data of mental

effort during instruction were only logged for 6 participants in each condition. Effect sizes are expressed in terms of omega-squared (w^2).
Table 1 shows the mean scores and standard deviations of the dependent variables for all conditions. The mean score on the prior knowledge test over all conditions was 7.60 (SD = 2.62), indicating that the participants were not novices in the domain (the maximum score was 12). We began our analysis with testing measures that should possibly be used as covariates for further analyses. ANOVAs with the factors level of perceived control and instructional method revealed no main effects and no interaction effect on prior knowledge (all $F(1, 84) < 1$, *ns*); no main effects (all $F(1, 84) < 1$, *ns*) and no interaction effect ($F(1, 84) = 1.88$, $MSE = 84{,}695.79$, *ns*) on instruction time, and no main effect of level of perceived control ($F(1, 84) < 1$, *ns*), instructional method ($F(1, 84) = 1.47$, $MSE = 149{,}871.54$, *ns*), or their interaction ($F(1, 84) < 1$, *ns*) on time on transfer tasks. Therefore, scores were analyzed with 2 x 3 ANOVAs.

With regard to performance on the transfer tasks, a main effect of level of perceived control was observed ($F(1, 84) = 4.29$, $MSE = 6.73$, $p = .041$, $w^2 = 4\%$). Learners in the conditions with a high level of perceived control performed better on transfer than learners in the conditions with low perceived control (in order, M = 5.46, SD = 2.74 and M = 4.32, SD = 2.42). Neither a main effect of instructional method ($F(1, 84) < 1$, *ns*) nor an interaction between level of perceived control and instructional method ($F(1, 84) = 1.03$, $MSE = 6.73$, *ns*) was found.

On mental effort during instruction, no effects were found of level of perceived control, instructional method, and their interaction (all $F(1, 30) < 1$, *ns*). Finally, also no effects were found of level of perceived control ($F < 1$, *ns*), instructional method ($F(1, 84) = 2.07$, $MSE = 3.00$, *ns*), and their interaction ($F(1, 84) = 1.21$, $MSE = 3.00$, *ns*) on time on transfer tasks.

Discussion

The results clearly confirm our first hypothesis, stating that learners whose expectation regarding control matches the control they can actually exert, perform better on transfer tasks than learners whose expectation is not met. In the present study all learners were told that they could select the order of problems, but

Table 1. Mean scores and standard deviations on prior knowledge and the dependent variables for all conditions

	Low level of perceived control						High level of perceived control					
	Study/Practice		Practice/Study		Study/Study		Study/Practice		Practice/Study		Study/Study	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Performance prior knowledge test (0 -12)	7.35	2.34	7.71	2.37	7.14	2.72	7.14	2.47	8.42	2.47	7.66	2.96
Instruction												
Instruction time (s)	2,265	347	2,138	287	2,010	180	2,153	257	2,140	313	2,216	337
Mental effort during instruction (1-9)	3.25	1.78	4.00	2.54	3.00	1.09	2.80	.97	4.00	1.89	3.85	1.80
Transfer Test												
Performance on transfer (0-12)	4.12*	2.32	5.12*	2.82	3.72*	1.97	6.05*	2.84	5.19*	2.93	5.12*	2.53
Mental effort on transfer (1-9)	4.35	1.95	4.23	1.75	5.37	1.33	3.97	2.27	5.00	1.65	4.86	1.13
Time on transfer tasks (s)	937	412	837	476	939	330	1,067	486	835	343	1.041	184

Note: mental effort during instruction is based on data of 6 participants per condition. Scores with * differ statistically, the High level of perceived control conditions perform better on transfer than the low level of perceived control conditions.

learners in the low perceived control conditions nevertheless received the problems in a fixed order. It can be argued that this inconsistency may have led to demotivation and thus in less willingness to invest effort in genuine learning. Our results further support the assumption that the effectiveness of learner control is –at least partly- contingent on differences between expected level of control and the control that can actually be exerted.

An implication of providing learners with control over problem selection is that they indeed show different sequences of selecting problems, so that the higher performance of learners with high perceived control may be attributable to these different sequences rather than the (mis)match between expected and actual control. For this reason we further analyzed the sequences of selecting problems in the conditions with high perceived control. From the 45 participants in these conditions, 32 participants selected the order of the problems precisely as it was presented (see Figure 2), which was the same as the fixed order of the problems in the low perceived control conditions. Thus, in these cases, learners started with the button at the top, then the button below it, until they finally reached the button at the bottom of the list. When only the 32 learners are taken into account who selected the problems in precisely the same order as they were presented in the low perceived control conditions, the high perceived control conditions still yield higher performance on the transfer tasks (M = 5.62, SD = 2.67 in the high perceived control conditions vs. M = 4.28, SD = 2.50 in the low perceived control conditions). Consequently, the difference between the high and low perceived control groups cannot be explained by differences in problem sequences.

The results failed to confirm the second hypothesis which predicted that learners in the study-practice conditions would perform better on transfer tasks than learners in the study-study conditions and practice-study conditions. This hypothesis was based on the assumption that the learners were novices. However, as the prior knowledge test indicated the learners in this experiment already possessed some knowledge in the domain. There is accumulating evidence that the effectiveness of instructional guidelines depends on the level of domain knowledge of learners (Kalyuga, 2005; Kalyuga, Ayres, Chandler, & Sweller, 2003; Reisslein et al., 2006). In fact, guidelines that are effective for novices in a domain may prove to be ineffective or even detrimental when applied to more proficient learners. Learners in the practice-study conditions may have had sufficient prior knowledge to manage the cognitive load imposed when they first had to practice a problem and construct an incomplete schema. By studying the associated animated model they could adjust their (incomplete) schema. On the other hand, the level of prior knowledge of learners in the study-study conditions enabled them to construct an initial schema that they could subsequently refine during the second study of the animated model. In other words, with this level of prior knowledge (i.e., the participants were neither novices nor proficient learners in probability calculation) it seems to be difficult to discern differences between solving problems and studying solutions of problems.

From a theoretical point of view the results contribute to cognitive load theory. Traditionally, cognitive load theory has focused on instructional designers and teachers making instructional decisions for their learners, rather than self-directed learners making instructional decisions for their own. Nevertheless there are situations in which a much more prominent role for the learners seems appropriate, for example, when their expertise is high (Paas et al., 2003) or when they are expected to design their own learning trajectory in the context of lifelong learning. Until now, one of the premises of cognitive load theory comprises that specific instructional design guidelines aim at specific types of learning activities, that is, no or very little variety in learning activities is expected. As a consequence the pattern of extraneous and germane cognitive load is rather determined. In lifelong learning contexts, however, the allocation of effort toward learning activities is also driven by individual motivational processes, such as personal goals and interests (Fisher & Ford, 1998). For this reason, Gerjets and Scheiter (2003) have proposed an augmented model of cognitive load in which learner goals and processing strategies moderate between the instructional design and the pattern of cognitive load. If learner control is included in this augmented model of cognitive load, the results of the present study suggest that learner expectations regarding control should certainly be incorporated in the augmented model.

It is conceivable that differences in mental effort during instruction failed to occur because of differences in the patterns of extraneous and germane cognitive load between the conditions. The applied mental effort measure used did not differentiate between mental effort due to the perceived difficulty of the subject matter, the presentation of the instructional material, or being engaged in relevant learning activities. It is possible that effects on perceived mental effort of the level of perceived control and the instructional method have neutralized each other. For example, the low perceived control conditions may have imposed rather high extraneous load combined with low germane load, whereas the high perceived control conditions may have imposed rather low extraneous load combined with high germane load. In effect, these would yield the same mental effort measure.

From a practical point of view our results have clear implications as well. The development of learning environments that respond to actions and choices of learners can be quite laborious and is therefore relatively expensive. Designers of such environments have to take into account how they deal with the expectations of the learners that are going to use the learning environment. If learners' expectations are not met, this might seriously endanger the effectiveness of the learning environment.

The findings and conclusions provide directions for future research. In this study a difference between high and low perceived control was enforced by telling learners beforehand that they could control the selection of tasks. Learners in the conditions with low perceived control gradually discovered that they could not really control the selection of tasks, whereas learners in the conditions with high perceived control could actually select the problems as they were told beforehand. However, it is not clear to what extent these learners indeed experienced a mismatch between expected and actually exerted control. For this purpose a valid and reliable instrument needs to be developed that measures the level of perceived control.

Finally, the results of this study are limited because of the limited scope of the instructional material (i.e., probability calculation with a focus on procedural knowledge rather than cause-and-effect explanations). In addition, specific learners (i.e., pupils of pre-university education) were used who already had some prior knowledge in the domain of probability calculation. The results were also limited because the assessment took place immediately after the instruction and, consequently, nothing can be concluded about mid-term and long-term effects. Future research is needed to determine whether the results can also be found in other domains, with another population of learners, and with delayed assessment of transfer of learning.

To conclude, the results of this study suggest that giving learners control over the selection of tasks might have positive effects on learning and transfer, provided that the given control matches the level of control that learners expect.

Chapter 6 – General Discussion

Animated models use animations and explanations to teach how a problem is solved and why particular problem-solving methods are chosen to solve it. In addition, a pedagogical agent supports the learner, for example, by directing the learner's attention to the relevant parts of the animation. However, novices may not possess the prior knowledge necessary for adequately processing an animated model. Cognitive load theory has proposed design guidelines to facilitate the processing of animated models, that is, to prevent cognitive activities due to poor design (i.e., decrease extraneous cognitive load), and to use the released cognitive capacity for genuine learning activities (i.e., increase germane cognitive load). The main focus of this thesis was: How to optimize cognitive load for learning from animated models? Three sub questions were discerned in this research question. First, it was investigated how extraneous cognitive load -due to poor design- could be minimized. Second, it was investigated how learners could be prompted to engage in activities that foster genuine learning. Third, factors were investigated that moderate the effects of design guidelines (either aiming at decreasing extraneous cognitive load, increasing germane cognitive load, or both). In the previous Chapters, five studies were presented in which an integrated theoretical framework for the design of animated models was defined (Chapter 2), design guidelines were investigated to decrease extraneous cognitive load (Chapters 3), design guidelines were investigated to increase germane cognitive load (Chapters 4 and 5), and factors were studied that moderated the effects of these design guidelines (Chapters 3 and 5). In the remainder of this Chapter the main results of these five studies are reviewed. Furthermore, the theoretical and practical implications of the findings are discussed. Finally, some directions for future research are suggested.

Review of the Results

The purpose of Chapter 2 was to construct an integrative framework for the design of animated models. First, an analysis was conducted on the constituent parts of animated models: Modeling, animations, and pedagogical agents. Next an extensive review was conducted on design guidelines originating from research in the field of cognitive load theory and multimedia learning. This review provided three sets of design guidelines applicable to animated models. The purpose of the first set of guidelines was to support learners to manage the complexity of the subject matter (i.e., manage intrinsic cognitive load). The second set of guidelines addressed methods that would help learners not to engage in activities hampering learning (i.e., decrease extraneous cognitive load). The third set of design guidelines aimed at helping learners to engage in activities that do contribute to genuine learning (i.e., increase germane cognitive load). Finally, mediating variables were reviewed that mitigate or strengthen the effects of the various design guidelines (e.g., motivation). The review yielded an integrative theoretical framework that interrelated the major concepts from cognitive load theory, the design guidelines, and the factors moderating the effects of those guidelines (see Figure 2 in Chapter 2). The experiments presented in the Chapters 3, 4, and 5 stem from this framework.

Chapter 3 further elaborated on the proposed design guidelines for decreasing extraneous cognitive load. In particular, guidelines for the pacing, structure, and modality of presented information were investigated. In general, it can be concluded that learners who have control over the pacing of segmented animated models perform poor compared to learners who have control over the pacing of continuous animated models. Two conclusions were drawn from this finding.

The first conclusion concerns the poor performance in the learner paced segmented condition. This might be attributed to the fact that learners were not able to exert full control over the animated model, that is, the pacing enabled them to control the presentation of the segments (i.e., the onset of a segment), but they could not segment the animated model in a way that was appropriate for them. This may have aroused a cognitive dissonance that could not be resolved and hence influenced their willingness to invest effort in learning. A similar effect appeared in the study described in Chapter 5, this time not on the level of a single animated model, but on the level of a range of models or problems for which learners had control over the order in which they were presented. Learners who thought beforehand that they could control this order, but discovered later that they could not actually exert this control, performed worse than learners who were able to control the order as they expected beforehand.

The second conclusion refers to the remarkable differential effect of modality. In the first study of Chapter 3, which used spoken explanations, the superiority of learner paced continuous animated models over learner paced segmented animated models was evident for near transfer performance (i.e., problems equal to the problems solved in the animated models), but not for far transfer performance (i.e., problems different from the ones solved in the animated models). The second study of Chapter 2 used written explanations and revealed that the superiority of learner paced continuous animated models over learner paced segmented animated models was only found for far transfer performance, whereas no differences were found for near transfer performance. These findings lend support to the assumption that learning pacing enables learners to strategically read written explanations and construct more elaborated cognitive schemas, which enabled them to solve far transfer problems (see also Tabbers et al., 2003). A similar reversed pattern with respect to the modality effect was found in the study described in Chapter 4. This study investigated if the use of reflection prompts stimulated learners to engage in real learning activities. For this study another perspective was taken on the modality effect, namely, that written explanations automatically receive less attention and effortful processing than spoken explanations (Foos & Goolkasian, 2005). It was hypothesized that reflection prompts would direct the learners' attention (i.e., incite them to mentally rehearse the text) and stimulate them to effortfully process the information (i.e., reflect on the text), but that it would only be effective when written explanations rather than spoken explanations were involved. Indeed, it was found that the use of reflection prompts canceled the modality effect, that is, annulled the differences between spoken and written explanations.

As mentioned earlier, the study presented in Chapter 5 further elaborated and confirmed the findings of the two studies presented in Chapter 3, namely, that learner control is ineffective when learners beforehand expect more control than they can actually employ later. The study of Chapter 5 also builds on the finding of Chapter 4 that design guidelines prompting active processing (e.g., reflection prompts) can be an effective instructional method. Active processing is also involved when learners have to solve problems themselves. In Chapter 5 it was hypothesized that a learning arrangement in which learners first had to study an animated model and then solve the same problem (i.e., active use of previously acquired knowledge would be more effective than arrangements in which learners had to study an animated model twice, or first had to solve the problem and only then study the animated model). The results, however, showed no differences between the learning arrangements which was probably due to the rather high level of prior knowledge of the participants.

Summarized, the results support three conclusions with respect to the three research questions of this thesis. The first research question concerned design guidelines to decrease extraneous cognitive load. The application of spoken explanations and segmentation in conjecture with pacing are typically propagated in order to decrease extraneous cognitive load (see Chapter 2). However, the results described in Chapter 3 provide a more detailed picture. The combination of segmentation and learner pacing was far less effective than in other studies. It seems that learning pacing combined with segmentation may have induced cognitive dissonance for the learners, because pacing over predefined segments only provides a very limited amount of control. This probably imposed a high extraneous cognitive load. Learner pacing with continuous animated models, on the other hand, enabled learners to employ full control and to segment the information in a way that suited them best.

The second research question referred to design guidelines fostering genuine learning. Here, the results are less straightforward and require more research in the future. The provision of reflection prompts may be an effective method to incite learners to relevant learning. However, it seems to be effective only when written explanations are involved. The results indicate that written explanations are effective when learners are prompted to attend and effortfully process the animated model. In this case the superiority of spoken explanations (i.e., the modality effect) disappears. It was also found that alternating between studying an animated model and then solving the equivalent problem did not foster learning, at least not with learners with some relevant prior knowledge of the learning domain.

The third research question referred to factors that weaken or strengthen the effects of design guidelines. The results described in the Chapters 3 and 5 make clear that the effects of the guidelines are contingent on the consonance between expectations of learners regarding the level of control in the learning environment

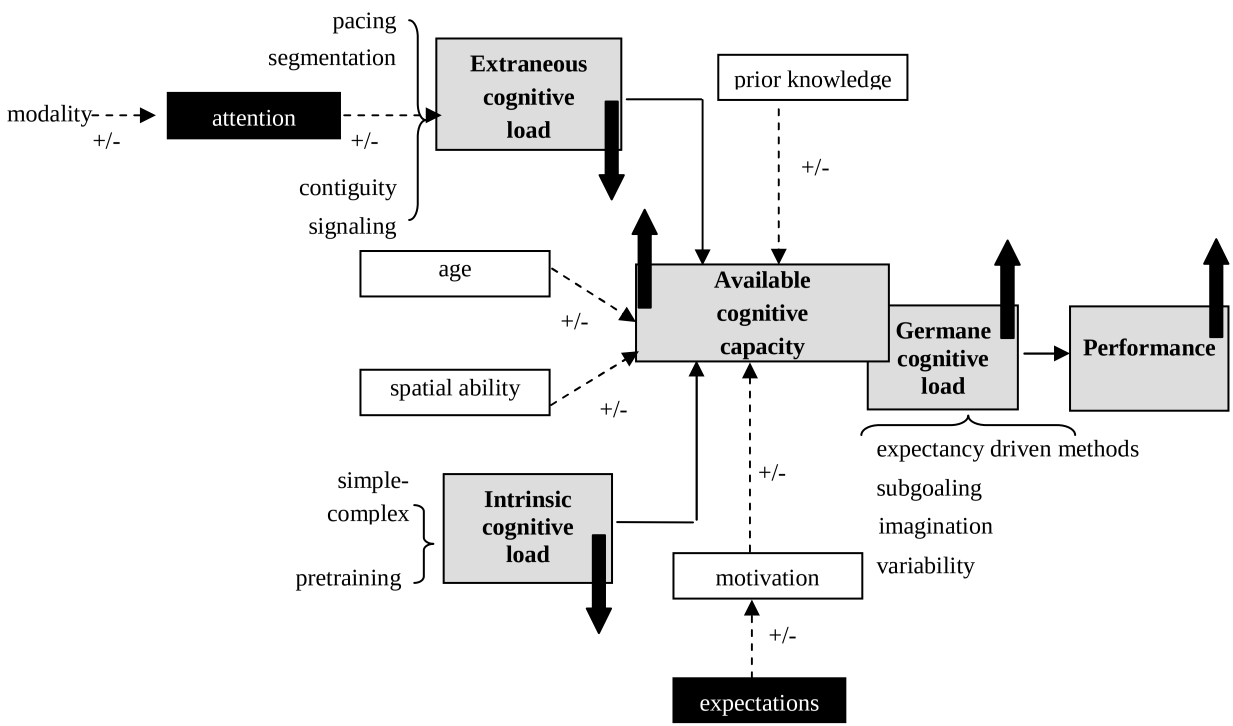

Figure 1. *The adapted integrative framework for the design of animated models. Black rectangles represent the adaptations. Grey rectangles represent dependent variables. White rectangles with discontinuous arrows represent moderating factors. Continuous arrows represent causal relations*

and the level of control they can actually exert. Particularly, when learners expect more control than is granted, their transfer performance deteriorates. In Figure 1 the results as described above are incorporated in the integrative framework for the design of animated models described earlier in Chapter 2. The adaptations are presented as black rectangles. Expectations of learners may influence their motivation and thus increase or decrease the cognitive capacity they employ for real learning (i.e., for activities that impose germane cognitive load).

The level of attention is –at least partly- contingent on the modality of presentation. This is indicated by the +/- symbol: Spoken explanations draw more attention than written explanations. This level of attention may influence the perceived extraneous cognitive load of learners (indicated by the +/- symbol).

Theoretical implications

The findings of this thesis put a new light on explanations of the modality effect. In theories like Mayer's cognitive theory of multimedia learning, the modality effect is assumed to occur because working memory is used more effectively if pictorial information is processed in the visual channel and simultaneously presented verbal explanations are processed in the verbal channel. However, it can be argued that a full explanation of the modality effect should also consider the characteristics of the media used. Spoken texts are linear – it is not possible for listeners to 'go back' to earlier presented words. Readers, on the other hand, are free to control the parameters of time (the duration of fixation on words) and space (the words they fixate on) when they process written texts (see also Rickheit, Stroher, & Müsseler, 1987). In this respect, system paced conditions may favor the characteristics of spoken texts. The superiority of spoken texts above written texts may diminish or even disappear when learners are enabled to take full advantage of the characteristics of written texts. Support for this argument was provided earlier by Tabbers et al. (2002, 2004), who gave learners control over pacing, which enabled them to read explanatory texts more strategically (i.e., select words, skip details). The findings of the second study presented in Chapter 3 also show that the learner paced continuous condition outperformed the computer paced continuous condition on far transfer performance when written texts were used, suggesting that learner pacing enables learners to process written texts better. In Chapter 4 it was argued that written texts automatically receive less attention than spoken texts. The consequence of devoting less attention is that readers have less opportunity to take full advantage of the characteristics of written texts. But when learners are explicitly prompted to actively attend to written texts they have more opportunity to determine which words or parts of the text, and for how long, they need to fixate on to enable adequate processing.

The results described in this thesis further emphasize the need to incorporate factors in cognitive load theory that mediate the effectiveness of design guidelines (Bannert, 2002; Gerjets & Scheiter, 2003). In a traditional interpretation of cognitive load theory a design guideline is supposed to induce a specific activity from the learner. From this viewpoint, the pattern of intrinsic, extraneous, and germane cognitive load is fully determined by the applied design guidelines. For example, the purpose of the imagination guideline is to foster the construction and automation of a cognitive schema and it is thus supposed to impose germane cognitive load. This might be true for more proficient learners, but recent research on cognitive load theory has shown that design guidelines that are beneficial for novice learners can be ineffective or even detrimental when applied to experts (i.e., the ‘expertise reversal effect’; Kalyuga, 2005; Kalyuga, Ayres, Chandler, & Sweller, 2003). For novices, imagination is probably too difficult and mainly imposes extraneous rather than germane cognitive load. In line with the expertise reversal effect, the results of this thesis further ground the notion that whether learners experience intrinsic, extraneous, or germane cognitive load does not depend solely on the type of design guideline implemented, but also on other factors such as learners’ prior knowledge (see also Gerjets & Scheiter, 2003). The results described in Chapters 3 and 4 about learners’ expectations make clear that the effectiveness of a design guideline may be dependent on the match between the actual function of the design guideline and the learners’ expectations with respect to this functionality.

Our findings with regard to learners’ expectations also have implications for theories about learner control. From a cognitive perspective, learner control has been propagated since it may help learners to adapt the learning material to their cognitive needs (e.g., by slowing down the pace of an animated model) and thus prevent an overload of their cognitive system (Niemiec, Sikorski, & Walberg, 1996; Williams, 1996). On the other hand, learners with less prior knowledge can easily become demotivated because they are overwhelmed by the freedom to choose. Moreover, motivation theories have stated that intrinsic motivation is one of the main components of the perceived control of a task (see, for example, Deci & Ryan, 1987). When learners perceive more control over a task their intrinsic motivation will probably increase and thus have a positive effect on the quality of learning (see Becker & Dwyer, 1994, for an example on hypermedia). The importance of perceived control is also found in research in organizational and industrial psychology, showing that the perception of workers on job autonomy is strongly associated with performance, job satisfaction, and motivation. It may be argued that the perception of control is –at least partly– determined by the expected control and the actual control. The results of this thesis clearly suggest that a theory describing the effectiveness of learner control should include the effect of learner expectations on learner control.

Practical implications

In addition to theoretical implications, some practical implications for multimedia designers follow from the results presented in this thesis. As has become clear, written explanations have more learning potential than one might expect from earlier multimedia studies. This provides opportunities for learning and training situations in which spoken explanations are not feasible. In particular, this seems promising for education to the hearing-impaired: Animated models with written explanations and reflection prompts foster learning just as well as animated model with spoken explanations (either with or without reflection prompts).

The findings presented in this thesis also suggests designers of multimedia learning environments to give learner control a second thought. Most reviews on learner control report inconclusive findings (for reviews, see Kay, 2001; Lin & Hsieh, 2001; Niemiec, Sikorski, & Walberg, 1996; Williams, 1996). One of the reasons for the mixed findings may be the fact that expectations of learners regarding control are not taken into account. The development of learning environments that respond on actions and choices of learners can be quite laborious and is therefore relatively expensive. Designers of such environments have to take into account how they deal with the expectations of learners who will work in the learning environment, because learner expectations with regard to control should be met in order to make the environment effective.

Future research

The studies reported in this thesis revealed some interesting findings that need to be further investigated. In general, effect sizes were consistent but rather low. In some cases this was probably due to the small number of participants (Study 1 in Chapter 3 and Chapter 5). A replication of these results in studies with more participants in each condition may yield higher effect sizes. In other cases methodical drawbacks of the experiments have limited the interpretation of results. Additional studies are required to provide more substantial support to the conclusions. For example, in Chapter 3 two separate studies were described which were different with respect to the modality used. Since two separate experiments were involved, conclusions regarding modality could only be drawn with caution. Therefore, a replication of the observed interaction effects in a study with an integrated factorial design with the factors modality, pacing, and structure would be welcome.

As discussed earlier, learning was hampered when learners expected more control than they were allowed to exert. However, it is not yet clear how learning is influenced when the mismatch is reversed, that is, when learners can exert more control than they expect beforehand. Although the studies in Chapter 2 indicate that learning is not hampered, more research is required to further strengthen the hypothesis that the effect of learner control is contingent on the learner expectations regarding control. Moreover, in this thesis it has been assumed that learners become demotivated when they expect more control than is granted, but the effect of expectations on motivation was not directly measured. Therefore, there is a need for instruments that measure the expectations of learners regarding control, as well as the effects of a mismatch between expected and granted control on task involvement. For both measurement instruments some preparatory work has already been conducted. The work of Ajzen (2002) may prove to be a useful point of departure for measuring the expected level of control. And for measuring task involvement, that is, the effects of applying design guidelines on learner motivation, a useful starting point is available in the work of Paas, Tuovinen, van Merriënboer, and Darabi (2005).

A third avenue for future research concerns the generalizability of the results of this thesis. Are the presented results also valid for other types of multimedia learning? Problem solving in probability calculation is rather procedural in nature, that is, it applies consecutive steps in order to solve the problem. However, cause-and-effect systems, such as the working of a bicycle pump, cylinder brakes, or electrical charges in a thunderstorm, involve knowledge about its components and knowledge about the behavior or the interaction of these components. More research is required to investigate whether the role of attention in modality and the hypothesis that expectations regarding control should match the actual control that can be employed, also apply to these other types of multimedia learning.

In Chapter 2 design guidelines were presented for managing intrinsic cognitive load, but none of these design guidelines were investigated in this thesis. In particular, extraneous cognitive load and germane cognitive load were considered to be communicating vessels as the reduction of extraneous load frees up cognitive resources for a possible increase in germane load. However, it can be argued that a temporary decrease in intrinsic cognitive load (e.g., by applying pretraining) may also release cognitive capacity that might consequently be exerted for activities fostering learning. This implies that a more comprehensive understanding of the interaction between the three types of cognitive load is necessary, and that the effects of design guidelines aiming at managing intrinsic cognitive load need also to be investigated to reach a complete integrative framework. The same argument applies to the moderating or mediating factors. In this thesis some evidence was found for the hypothesis that expectations of learners affect their motivation and thus their willingness to invest in genuine learning. The moderating role of prior knowledge in the effectiveness of design guidelines has been well established, and also with respect to the moderating role of age several studies have been conducted (see for an overview, Paas, van Gerven, & Tabbers, 2005). However, a further qualification of the integrative framework for the design of animated models requires that additional moderating factors such as spatial ability and cognitive style (e.g., verbalizers vs. visualizers) are further investigated.

Finally, three out of four significant effects presented in this thesis are interaction effects. This is in line with results reported in other studies (see Chapter 2 and Wouters, Tabbers, Paas, 2007 for examples). Probably, this points to a new focus in cognitive load theory and theories of multimedia learning according to which it is not only investigated if particular design guidelines work, but especially under which conditions they are still effective. Moreover, it can be argued that when the results of experiments are brought into practice, combinations of design guidelines are likely to be applied (e.g., the modality and pacing design guideline). Therefore, future studies should investigate the effects of combinations of guidelines on learning in order to further advance cognitive load theory as well as the practical field of multimedia design.

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Short Summary

Observing how someone performs a motor skill, for instance, making the forehand strike in tennis, has proven to be an effective instructional method. A cognitive skill (e.g., solving a problem), on the other hand, is performed in someone's head and therefore in itself not observable. Such cognitive skills need to be explicated in order to become observable for learners. A teacher explaining on the blackboard how a math problem is solved explicates a cognitive skill so that it becomes observable for the learners. Unfortunately, such cognitive skills may involve abstract concepts and processes that are difficult to express in words (e.g., the concept of 'drawing with replacement' in solving a probability calculation problem). In these cases animated models can be used. In animated models, animations are used in conjecture with textual explanations to display how a problem is solved and why particular methods are chosen to solve it. A pedagogical agent may provide support, for example by pointing to the relevant parts of the animation. On the other hand, animated models can be problematic for novices since they not only have to cope with textual explanations, but also with transient animations and -last but not least- with the integration of those two types of information.

Cognitive load theory tries to align the structure of information and the way it is presented with human cognitive architecture. The theory further alleges that instructional designers should take care of three kinds of cognitive load that learners experience when they perform instructional tasks, such as learning from animated models. Intrinsic cognitive load, related to the amount of interactive elements in the learning material that have to be processed; extraneous cognitive load, related to the cognitive activities that do not contribute to the learning process; and germane cognitive load, related to the cognitive activities that strengthen the learning process. The general goal for instructional design is to reduce extraneous load to a minimum, and maximize germane load to a level that remains within working memory limits. The aim of this thesis is to investigate how learning from animated models can be optimized. Beside an extensive analysis of design guidelines (Chapter 2), four experimental studies are presented in which instructional methods are investigated to decrease extraneous cognitive load

(Chapters 3 and 5) and to increase germane cognitive load (Chapters 4 and 5). Moreover, in the Chapters 3 and 5 it is investigated whether factors exist that weaken or strengthen the effects of the investigated design guidelines.

Chapter 2 provides a theoretical account of what animated models comprise and why they are an effective instructional method. Three components are distinguished: Modeling, animations, and pedagogical agents. Modeling enables learners to construct an initial schema of how to solve a problem, without engaging in a time-consuming and error-prone learning process. Afterwards they can elaborate this initial schema by performing the skill themselves. Animations can be used to visualize abstract concepts and processes in problem solving. Characteristic for animations is that many changes occur simultaneously, which may be very confusing for novices. A pedagogical agent can provide support by guiding learners' attention to relevant aspects of the animation or by asking questions by which they can test their understanding. Moreover, the implications of cognitive load theory for animated models are extensively discussed. The larger part of the chapter covers an extensive review of potential design guidelines for learning from animated models. This results in three sets of guidelines that aim for managing intrinsic cognitive load, decreasing extraneous cognitive load, and increasing germane cognitive load. In addition, some learner characteristics are identified that have proven to be moderators, that is, they mitigate or strengthen the effects of specific design guidelines. The chapter ends with the presentation of a theoretical framework in which cognitive load theory, the different design guidelines, and the moderating factors are related to each other. The studies described in the following chapters stem from this framework.

In Chapter 3 two explorative experiments are presented which investigated whether pacing, structure, and modality design guidelines are effective to minimize extraneous cognitive load. In the first experiment 60 pre-university students were randomly assigned to one of four conditions varying in pacing (the animated models were either learner paced or computer paced) and structure (the animated models were either segmented or continuous). In all conditions spoken explanations were used. Participants observed 8 animated models displaying how problems in the domain of probability calculation were solved. Next they completed a transfer test consisting of 8 near transfer tasks (the problems were similar to the problems solved in the animated models) and 4 far transfer tasks (the problems were different from the problems solved in the animated models). During the instruction and the transfer test a self-report mental effort measure was administered. The results showed that participants in the learner paced continuous and the computer paced segmented conditions outperformed the learners in the learner paced segmented condition on near transfer. The second experiment, with 78 pre-university students, used the same design as the first experiment with the exception that written explanations were used. This time the results showed that participants in the learner paced continuous condition outperformed learners in the learner paced segmented and the computer paced continuous conditions on far transfer. Apparently, effective learner pacing is only to occur with continuous animated models when the expected level of control corresponds with the given level of control, and not with segmented animated models.

Chapter 4 investigated whether the use of reflection prompts enables learners to engage in activities that contribute to genuine learning. Point of departure was the assumption that the modality effect occurs because visual signals, such as written text, do not receive as much attention as spoken signals and therefore are processed with less effort. Furthermore, it was argued that reflection prompts would direct the learner's attention to the written explanation yielding effortful processing. On the other hand, it was assumed that spoken explanations would automatically receive sufficient attention and that reflection prompts would have no effect. The hypothesis was that reflection prompts would only be effective for written explanations and that, consequently, the difference between spoken and written explanations (i.e., the 'modality effect') would disappear. In total 96 participants of pre-university education were randomly assigned to one of four conditions consisting of the factors modality (either spoken of written explanations) and reflection prompts (learners were either prompted to reflect on an animated model or not). Participants observed 8 animated models displaying how problems in the domain of probability calculation were solved. Next they completed a transfer test consisting of 12 transfer tasks. During the instruction and the transfer test a self-report mental effort measure was administered. The results confirmed the hypothesis, that is, the modality effect disappeared when reflection prompts were combined with written explanations.

Chapter 5 further investigated the findings of the studies described in Chapters 3 and 4. First, it was tried to replicate the finding of Chapter 3 that learners engaged in less genuine learning when they expected more learner pacing than they could actually employ. Second, it built on the observation of Chapter 4 that supporting learners to actively process instructional material had a beneficial effect on learning from animated models. The participants were 90 students from pre-university education who were randomly assigned to one of six conditions consisting of the factors perceived level of control (students were told they could control the learning environment, whereas actually they could not exert this control vs. students were told they could control the learning environment and they could indeed exert this control) and instructional method (learners first observed an animated model and then solved the same problem, they first solved the problem and then observed the animated model, or they observed the same animated model twice). Participants were presented 8 problems in the domain of probability calculation. The learning control in this experiment concerned the order in which the problems could be selected. Afterwards, participants completed a transfer test consisting of 12 transfer tasks. During the instruction and the transfer test a self-report mental effort measure was administered. The results show that learning impedes when learners expect control that they cannot employ in the learning environment. This is ascribed to the insoluble cognitive dissonance occurring because of the inconsistency between the expected and actual level of control. No effect of instructional method was found which is attributed to the relatively high level of prior knowledge of the learners in this experiment.

The final chapter presents a general discussion. First, an outline is given of the results. In general, animated models seem to be most effective when learners do not expect more control over the animated models than is actually granted. This is evident in the superior performance of learners who worked with self-paced continuous animated models. Furthermore, the results make clear that there is no difference between spoken or written explanations when learners are prompted to actively pay attention to the written text and thus take full advantage of the characteristics of written media. The design used to stimulate learners to engage in real learning activities, alternating between first studying an animated model and then solving the same problem, did not yield better learning. These results have some theoretical and practical implications. It is suggested that the modality effect can only be explained if the characteristics of spoken and written media and the methods to support these characteristics are taken into account. Moreover, the results support the idea that cognitive load theory needs to be augmented with variables that moderate or mediate the effectiveness of design guidelines. More specifically, the results support the view that learners' expectations should be taken into account in theories about learner control and multimedia design. A practical implication, following from the observation that written explanations can be just as effective as spoken explanations, is that animated models can be used in the education of the hearing-impaired. The chapter concludes with suggestions for future research.

Korte samenvatting

Het observeren van iemand die een motorische vaardigheid uitvoert, bijvoorbeeld het maken van de forehandbeweging in tennis, kan een effectieve instructiemethode zijn. Cognitieve vaardigheden, zoals het oplossen van problemen, zijn echter niet observeerbaar wanneer ze niet eerst expliciet gemaakt worden. Een docent die op het bord uitlegt hoe een wiskundeprobleem het best opgelost kan worden, maakt deze cognitieve vaardigheid expliciet en daardoor observeerbaar voor de leerlingen. Helaas hebben cognitieve vaardigheden vaak betrekking op abstracte begrippen of processen (denk bijvoorbeeld aan het begrip 'trekking met teruglegging' in de kansberekening) die moeilijk in woorden uit te leggen zijn. In dat geval kunnen animated models een oplossing zijn. In animated models worden animaties gecombineerd met tekstuele uitleg om te laten zien hoe een probleem wordt opgelost en waarom bepaalde methoden daarvoor het meest geschikt zijn. Een pedagogische agent kan daarbij ondersteuning aanbieden, bijvoorbeeld door te wijzen naar relevante aspecten van de animatie of door vragen te stellen waardoor de leerlingen hun kennis kunnen toetsen.

Aan de andere kant kunnen zulke animated models problematisch zijn omdat beginnende leerlingen twee soorten informatie moeten integreren: De animatie en de daarbij behorende tekstuele uitleg. De cognitieve belastingtheorie houdt zich bezig met de vraag hoe informatie en de manier waarop die gepresenteerd wordt afgestemd kan worden op de kenmerken van de menselijk cognitieve architectuur. De theorie stelt verder dat ontwerpers van instructie rekening moeten houden met drie soorten belasting die leerlingen ervaren wanneer ze taken uitvoeren (zoals het leren van animated models).

Intrinsieke cognitieve belasting heeft betrekking op de complexiteit van de leerstof, dat wil zeggen het aantal informatie-elementen dat tegelijkertijd verwerkt moet worden; ineffectieve cognitieve belasting ontstaat wanneer leerlingen zich bezig houden met activiteiten die niet bijdragen tot leren; en effectieve cognitieve belasting komt voort uit cognitieve activiteiten die wèl bijdragen tot leren. Het doel van het ontwerpen van instructie is om de ineffectieve cognitieve belasting te minimaliseren en tegelijkertijd de effectieve cognitieve belasting te maximaliseren op een zodanige wijze dat de beschikbare capaciteit van het werkgeheugen niet overschreden wordt.

In dit proefschrift wordt onderzocht hoe het leren van animated models geoptimaliseerd kan worden. Naast een theoretisch hoofdstuk (Hoofdstuk 2) worden 4 experimentele studies gepresenteerd waarin ontwerprichtlijnen voor het minimaliseren van ineffectieve (Hoofdstukken 3 en 5) en het maximaliseren van effectieve cognitieve belasting (Hoofdstukken 4 en 5) worden onderzocht. Daarnaast wordt in de Hoofdstukken 3 en 5 onderzocht of er factoren aan te wijzen zijn die het effect van deze ontwerprichtlijnen kunnen versterken of verzwakken.

In Hoofdstuk 2 wordt nader ingegaan op de kenmerken van animated models. Drie componenten worden onderscheiden: Modelleren, animaties en pedagogische agenten. Met behulp van modelleren kunnen leerlingen zich een beeld vormen, dat wil zeggen een soort van mentale representatie, van hoe een probleem wordt opgelost en waarom bepaalde methoden het meest geschikt zijn zonder dat ze dit zelf moeten uitzoeken in een tijdrovend proces dat bovendien kan leiden tot fouten die later moeilijk ongedaan gemaakt kunnen worden. In een later stadium kunnen leerlingen die mentale representatie dan verder verfijnen door zelfstandig problemen op te lossen. Animaties kunnen gebruikt worden om abstracte concepten en processen tijdens het probleemoplossen aanschouwelijk te maken. Kenmerkend voor complexe animaties is dat er veel veranderingen tegelijk kunnen plaatsvinden wat met name voor beginnende leerlingen lastig is. Een pedagogische agent kan hen ondersteunen door bijvoorbeeld op belangrijke veranderingen in de animatie te wijzen of door een vraag te stellen waarmee leerlingen hun begrip kunnen testen. Ook worden in Hoofdstuk 2 de gevolgen van de cognitieve belastingtheorie voor animated models besproken. Het grootste deel van dit hoofdstuk betreft een uitgebreide review van mogelijke ontwerprichtlijnen voor animated models en factoren die daarop een modererende invloed hebben. Dit leidt tot drie verzamelingen van ontwerprichtlijnen voor achtereenvolgens (1) het beheersen van de intrinsieke cognitieve belasting, (2) het verlagen van de ineffectieve cognitieve belasting en (3) het verhogen van de effectieve cognitieve belasting. Het hoofdstuk wordt afgesloten met een theoretisch kader waarin de cognitieve belastingtheorie, de besproken ontwerprichtlijnen en de modererende factoren met elkaar in verband gebracht worden. De experimenten in de Hoofdstukken 3 tot en met 5 volgen uit dit kader.

In Hoofdstuk 3 worden twee exploratieve experimenten beschreven die onderzoeken in welke mate het zelf bepalen van het tempo van het animated model en de structuur van het animated model de ineffectieve cognitieve belasting kunnen beperken. In het eerste experiment deden 60 leerlingen mee uit de bovenbouw van het voortgezet onderwijs (VWO 4). Zij werden op basis van toeval ingedeeld in een van de vier condities die gevormd werden door de factor tempo bepalen (het tempo van het animated model werd bepaald door de leerling of door de computer) en de factor structuur (het animated model was opgedeeld in segmenten met pauzes of werd ononderbroken gepresenteerd). In alle condities werd gesproken uitleg gegeven. De deelnemers observeerden 8 animated models waarin problemen op het gebied van kansberekening werden opgelost. Daarna kregen ze een transfertest die bestond uit 8 nabije transfertaken (de problemen kwamen overeen met de problemen die in de animated models waren opgelost) en 4 verre transfertaken (de problemen waren afwijkend van de problemen die in de animated models waren opgelost). Tijdens de instructie en de transfertest werd de deelnemers gevraagd aan te geven hoeveel mentale inspanning deze taken hadden gekost. De resultaten toonden aan dat leerlingen in zowel de conditie waarin zij zelf het tempo van ononderbroken animated models konden bepalen als de conditie waarin de computer het tempo van de gesegmenteerde animated models bepalen, hoger presteerden op nabije transfer dan leerlingen in de conditie waarin zij zelf het tempo van gesegmenteerde animated models konden bepalen. In experiment 2 deden 78 leerlingen mee uit de bovenbouw van het voortgezet onderwijs (VWO 4). Dezelfde opzet als in experiment 1 werd gebruikt met dit verschil dat de animated models voorzien waren van geschreven uitleg. De resultaten toonden aan dat leerlingen in de conditie waarin zij zelf het tempo van ononderbroken animated models konden bepalen hoger scoorden op verre transfer dan leerlingen in de condities waarin zij zelf het tempo van gesegmenteerde animated models konden bepalen en waarin de computer het tempo van ononderbroken animated models bepaalde. Blijkbaar is het zelf bepalen van het tempo van animated models alleen effectief als de mate waarin leerlingen het tempo kunnen bepalen overeenkomt met hun verwachtingen daaromtrent. Bovendien is het zelf bepalen van het tempo het meest effectief als de leerling volledige controle heeft, dat wil zeggen, dat ze ononderbroken animated models krijgen en niet vooraf gesegmenteerde animated models.

In Hoofdstuk 4 wordt een experiment gepresenteerd dat als doel had te onderzoeken of reflectieprompts leerlingen kunnen stimuleren tot cognitieve activiteiten die bijdragen tot leren. Uitgangspunt van het experiment was dat het modaliteitseffect optreedt omdat visuele signalen zoals geschreven tekst minder aandacht krijgen en daarom met minder inspanning verwerkt worden dan gesproken signalen. Verder werd verondersteld dat reflectieprompts de aandacht van de leerling op de geschreven uitleg zou vestigen en zo tot een betere verwerking van die uitleg zou leiden. Daarentegen werd verondersteld dat gesproken uitleg automatisch aandacht trekt en dat reflectieprompts hier geen effect zouden hebben. De hypothese was daarom dat reflectieprompts bij geschreven uitleg effectief zouden zijn en het verschil tussen geschreven en gesproken uitleg zouden opheffen. In totaal deden 96 leerlingen mee uit de bovenbouw van het voortgezet onderwijs (VWO 4). Ze werden op basis van toeval verdeeld over vier condities die gevormd werden door de factor modaliteit (uitleg bij animated models was geschreven of gesproken) en reflectieprompts (leerlingen werden wel of niet aangespoord te reflecteren op de animated models). De deelnemers observeerden 8 animated models waarin problemen op het gebied van kansberekening werden opgelost. Daarna kregen ze een transfertest die bestond uit 12 transfertaken. Tijdens de instructie en de transfertest werd de deelnemers gevraagd aan te geven hoeveel inspanning deze taken hadden gekost. De resultaten bevestigden de hypothese: het gebruik van reflectieprompts bij geschreven uitleg doet het modaliteitseffect verdwijnen.

Hoofdstuk 5 gaat verder in op twee bevindingen uit de experimenten die beschreven zijn in de Hoofdstukken 3 en 4. Ten eerste wordt geprobeerd het resultaat uit Hoofdstuk 3 te herhalen: Leerlingen leren minder wanneer ze meer controle over het tempo van de animated models verwachten dan ze feitelijk krijgen. Ten tweede wordt de waarneming uit Hoofdstuk 4, dat het ondersteunen van leerlingen in het actief verwerken van informatie een gunstig effect heeft op leren, verder onderzocht. De deelnemers waren 90 leerlingen uit de bovenbouw van het voortgezet onderwijs (VWO 4). Ze werden op basis van toeval verdeeld over zes condities die gevormd werden door de factor verwachtingen met betrekking tot controle (leerlingen werd verteld dat ze controle hadden over de leeromgeving terwijl ze dat feitelijk niet hadden vs. leerlingen werd verteld ze controle hadden over de leeromgeving en ze konden die controle ook daadwerkelijk uitoefenen) en de factor instructiemethode (leerlingen kregen eerst een animated model en losten hetzelfde probleem daarna zelf op vs. leerlingen losten eerst een probleem op en kregen daarna het animated model vs. leerlingen bestudeerden twee keer hetzelfde animated model). De deelnemers kregen 8 problemen op het gebied van kansberekening. De controle in dit experiment had betrekking op de volgorde waarin de problemen geselecteerd konden worden. Daarna kregen ze een transfertest die bestond uit 12 transfertaken. Tijdens de instructie en de transfertest werd de deelnemers gevraagd aan te geven hoeveel inspanning deze taken hadden gekost. De resultaten bevestigden de bevindingen uit Hoofdstuk 3 dat het leren gehinderd wordt wanneer leerlingen een bepaalde mate van controle verwachten die ze feitelijk niet kunnen uitoefenen. Er werden geen verschillen gevonden tussen de instructiemethoden en dus ook geen effect van het ondersteunen van leerlingen bij het actief verwerken. Waarschijnlijk is dit te wijten aan het relatief hoge voorkennisniveau van de leerlingen.

Het laatste hoofdstuk presenteert een algemene discussie. Eerst wordt een overzicht gegeven van de resultaten van de uitgevoerde experimenten. In zijn algemeenheid lijken animated models het meest effectief te zijn wanneer de verwachtingen die leerlingen hebben ten aanzien van controle overeenkomen met de controle die ze daadwerkelijk kunnen uitoefenen. Dat blijkt onder meer uit de goede prestaties van leerlingen die werkten met ononderbroken animated models die ze zelf konden pauzeren op plaatsen die zij belangrijk vonden. Verder blijkt uit de resultaten dat het niet uitmaakt of een animated model voorzien is van gesproken of geschreven uitleg, mits leerlingen gestimuleerd worden extra aandacht te besteden aan de geschreven tekst. Tenslotte is gekeken hoe leerlingen gestimuleerd kunnen worden om activiteiten uit te voeren die het leren bevorderen. Het ontwerp dat gebruikt werd om leerlingen te stimuleren om activiteiten uit te voeren die het leren bevorderen, eerst het bestuderen van een animated model waarin een probleem opgelost wordt en daarna het zelfstandig oplossen van hetzelfde probleem, leidde echter niet tot betere leerprestaties. Deze resultaten hebben zowel theoretische als praktische implicaties. Om te beginnen wordt gesuggereerd dat het modaliteitseffect alleen volledig verklaard kan worden als ook de kenmerken van gesproken en geschreven media en de methoden om die kenmerken te ondersteunen in het verklaringsmodel worden meegenomen. Daarnaast ondersteunen de resultaten de idee dat de cognitieve belastingtheorie uitgebreid dient te worden met variabelen die de effectiviteit van ontwerprichtlijnen kunnen beïnvloeden. In het bijzonder ondersteunen de resultaten de gedachte dat verwachtingen van leerlingen meegenomen moeten worden in theorieën over leerlingcontrole en multimedia-ontwerp. Een praktische implicatie, voortkomend uit het feit dat geschreven uitleg even effectief kan zijn als gesproken uitleg, is dat animated models ook gebruikt kunnen worden in het onderwijs aan doven of slechthorenden. Hoofdstuk 6 wordt afgesloten met een aantal suggesties voor toekomstig onderzoek.